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UNITED STATES DEPARTMENT OF AGRICULTURE

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H. C. TAYLOR, Chief

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THE RELATION OF LAND TENURE TO THE USE OF THE ARID GRAZING LANDS OF THE SOUTHWESTERN STATES

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INTRODUCTION.[1]

A large part of the land of the western half of continental United States, probably from one-half to two-thirds of the total area, can not be used for the growing of field crops, mainly because the rainfall which it receives is insufficient for the growth of any known cultivated plants. The precipitation, however, is enough for the production of a growth of native vegetation which furnishes excellent, though sparse, forage for grazing animals.

Practically all of this land is now in use as grazing land, and has been so used for the last 25 to 50 years. Because no other profitable use for the land has yet been found, the grazing industry has become one of the leading, if not the leading, industry in many of the Western States. It is probable that in the case of more than 95 per cent of the public land yet unreserved and unappropriated the failure to

[1] This bulletin has been prepared under the immediate direction of Dr. L. C. Gray, Economist in Charge of Land Economics, Office of Farm Management and Farm Economics. In the preparation of this bulletin the writer has used freely information obtained from many sources, some of which can not be referred to in the literature of the subject because it has not been published. He is very grateful for the courtesies extended, and takes this means of acknowledging his indebtedness and expressing his thanks.

appropriate is due to the fact that under existing laws the land could not be obtained in areas of proper size for efficient operation. There is little question as to the accuracy of this generalization, and it is basic to all of the conclusions that will be presented in this bulletin.

From the very beginning of the use of the arid grazing lands, the fact that our existing land laws were but poorly adapted to them has been pointed out,[2] but, so far, although attempts have been made to pass land laws that will fit the special conditions of the region, it is believed that the problem is not yet solved. The grazing industry which has grown up under these handicaps has now reached a stage in its development at which normal growth must cease and retrogression may be expected to occur if some legislation adapted to its needs be not passed.[3]

Because an increase in the total production of meat animals and their by-products is not only highly desirable but easily possible on these arid grazing lands under an improved system of management, it becomes important that the factors that enter into the problem be carefully stated.

Basic to a much needed general improvement in range management is legal right of some kind to definitive control of the land by the user, which must carry with it the right to subdivide the range lands with fences. The existing Federal land laws operate in such a manner as to make an open range system compulsory, though this result is purely incidental rather than the intent of the lawmakers. These laws were designed to suit other and entirely different conditions.

Enactment of the proper kind of legislation has been prevented hitherto, at least in part, by two sorts of public opinion, either or both of which may be changed by a better understanding of the entire problem. These opinions are held by two different groups of people—the general public of the thickly populated humid region and the stockmen of the western grazing region. The great majority of our people have little knowledge of or interest in the problem (in spite of the fact that they are intimately concerned), and, because of their environment, have no standards by which to judge the merits of this particular case. On account of the sad experiences of previous generations, they are afraid to permit individuals to have legal control of large areas of land. Yet the productivity of the lands under consideration is so small that the users must have control of very large areas in order successfully to carry on the only kind of agricultural industry the land will sustain. Stockmen, though vitally concerned, have been slow to give a vigorous expression

[2] Powell, J. W., Report on the Lands of the Arid Region of the United States. House Ex. Doc. 73, 45th Cong., 2d sess., 1878.

[3] This is as important to the consumer of meat as it is to the producer of range stock, though the former may not be aware of it.

of unified opinion as to what should be done. While local differences in the changes needed have been partly responsible for this condition, the main cause has been the fear that any changes might be unfavorable to them individually. Such conditions are now largely past, and opinion among the stockmen is becoming very definite. They know what is desirable and why it is necessary and are taking steps to inform the public.[4]

As an illustration of the results of the present system of land tenure in a specified region, extracts (with maps) from an unpublished report to the Secretary of Agriculture on "An Investigation of Conditions of the Grazing Land Lying within the Limits of the Atlantic and Pacific Railroad Land Grant"[5] are included in this bulletin. These extracts show (1) the character and distribution of the principal range plant associations which form the range stock feed of Arizona and New Mexico, (2) the character of the present legal tenure of the land within the boundaries of the Atlantic and Pacific Railroad Land Grant, (3) some data on the effects of the drought of 1917–18 in Arizona and New Mexico, with (4) a summary of the experience and opinions of some stockmen of that region. It must be understood that every region has its own plant associations which constitute the native forage crop, some of which are better and some poorer than those shown for New Mexico and Arizona; that the land tenure condition shown in the maps (figs. 3, 4, and 5) is about as complex as any that exists in the arid region; and that the drought of 1917–18 in Arizona and New Mexico was really not very severe nor long continued as compared with others that have occurred in that region. While a single concrete case taken from any region can not illustrate all the factors that must be recognized in a consideration of the whole problem, the most important factors are here presented with the force of a statement of actual fact in support of the conclusions reached. The area examined is so large that the conclusions reached are believed to possess great weight.

THE REGION.

The area to which the following generalizations directly apply is that part of the arid Southwest included in Arizona and New Mexico.

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[4] In presenting the ideas contained in this bulletin it will be necessary repeatedly to point out how this or that affects the range stock raising industry and stockmen. This continual reference arises from the fact, already stated, that the land will not sustain any other form of agricultural industry. Wherever this statement does not apply, the land is not arid grazing land in the sense in which the expression is here used. No attempt is made here to discuss dry farming conditions and practices. Though stock be grazed upon native grass pastures on such farms, stock raising is but one of the enterprises on what are essentially farms. The lands referred to in this bulletin are range grazing lands upon which the raising of stock is the only enterprise possible. (See page 7.)

[5] An investigation and report made by E. O. Wooton of the Office of Farm Management and Farm Economics, and Robert R. Hill, Grazing Examiner of the Forest Service, in 1919. During 1917 and 1918 a drought occurred in New Mexico and Arizona which resulted in a greatly diminished output of meat animals. The investigation was made to ascertain what might be done to reduce the consequent losses to a minimum and to prevent, as far as possible, a recurrence of such conditions.

SUMMARY.

CLIMATIC and other natural conditions so limit the utilization of a large part of the area of the 11 Western States that this area can not be used agriculturally for anything but range grazing. Yet our land laws are such that improvement in the use of the land for this purpose is very difficult, while continued misuse of large areas of both public and private grazing land is made, in effect, compulsory. This bulletin discusses the evils that arise in this connection and the remedies that have been suggested.

Extension of the homestead policy, by gradually increasing the area that may be homesteaded, has not solved the range problem, since that plan assumes the possibility of substituting some more complex type of agricultural use for the grazing industry that now occupies the land. Legislation which breaks up the use areas into holdings too small for economic use results in loss to all concerned without establishing a more productive industry than that now using the land. The homesteading of lands which may be profitably cultivated is a different matter; such lands are not included in this study, which deals only with arid grazing lands.

Sale and exchange of restricted areas, while valuable as a means of consolidating use areas, are at best but expedients of local application. The issuance of lieu land scrip for lands surrendered to the Government is of still more restricted use, as a general policy.

A leasing system, properly administered, has certain important advantages not possessed by any of the abovementioned methods of disposal.

A permit system, like that now in operation in the national forests (though not necessarily duplicating it), is probably the best system yet devised. Such a system would prevent the disruption of the existing industry, avoid the losses that result from enlarging the homestead area, recognize the equities of present users, giving proper adjustments of claims, protect and encourage the industry for which the region is adapted, set in motion a procedure that would automatically but gradually reduce the size of all excessively large holdings, and establish that individualized control of the lands under competent supervision which is so necessary for the further development of the live-stock industry on these arid grazing lands. Not the least of the advantages of the permit system lies in the fact that it does not of necessity interfere with nor replace the existing land laws, but makes easier the administration of these laws.

The illustrative material refers to all or a selected part of this area. Most of these statements apply more or less directly to a much larger region—the arid grazing lands of the Western States—which may be roughly outlined as including the great basin region (the southeastern corner of Oregon, the southwestern corner of Idaho, the part of Wyoming west of the Rocky Mountains, the part of California east of the Sierra Nevadas, and practically all of Nevada and Utah), all of Arizona and New Mexico, and the part of Texas west of the Pecos River (but not including the crop and forest lands within these boundaries).

The statements relative to the natural and managerial factors controlling the stock-raising industry will doubtless apply rather closely over all the region indicated. The conditions of land tenure and their consequences differ more or less with each State. Any recommendations as to changes in land policy must necessarily take these conditions into consideration.

About one-third of this great region, or approximately 200 millions of acres, is to-day open for entry by homesteaders—an area larger than the occupied land of the original 13 colonies when this Nation was founded. All of this land long ago would have passed to private ownership if it had been productive agricultural land or if there had been any way of getting control of large enough bodies of it for private use as grazing land.

The different classes of land.—On a basis of possible use the lands of the western United States may be classified in a broad way as follows (see bibliography, section 3):

"Desert" lands are those where the average annual rainfall is so small[6]—usually less than 6 inches—that there is very little if any permanent drinking water for stock, and consequently year long grazing is not practicable. Of course, cultivation of any known crop on this land without irrigation is an impossibility.

"Arid grazing lands" are those where yearlong or seasonal grazing is assured, but where any kind of cultivation of crops is possible only a small part of the time or not at all, and upon only a very small part of the area. The average annual rainfall of this area ranges from about 6 to 15 inches.

Where the average annual rainfall is from 15 to 20 inches cultivation of certain crops is often possible when topography, soil conditions, and the seasonal distribution of rainfall are favorable and the growing season is long enough; but the farm practices are those of the system called "dry farming" and the land is here called "semi-arid" or "dry-farming" land.

[6] The average annual rainfall is used merely as a rough means of limiting areas. It is not a good measure to use for anything more than such approximations, but it is the only one now available. It must not be taken to mean the amount of water available to growing plants.

The "humid region" [8][7] is that area in which some sort of crop may be produced on cultivated land every year. Except for small areas in the higher mountains to the south or on the higher plateaus or valleys to the north this humid region occurs east of the ninety-seventh meridian or west of the Cascade Mountains. Irrigated lands would fall in this class; although they are not in a humid region, the growing conditions supplied the plants are those of a humid region.

"Forests" and "woodlands" [8] are, as the terms imply, the tree-bearing areas. In the region under consideration they lie, for the most part, within the national forests. In so far as they have grazing uses they are now very properly treated as arid grazing land, with scattered small areas of dry-farming land interspersed. However, they are not considered as belonging in the area here referred to as arid grazing land which lies outside the national forests.

Of course, these subdivisions are more or less arbitrary, but they are necessary in order that we may consider the best utilization of the different regions with some degree of accuracy.

There is a belt or zone between the farming land of the humid region and that of the semiarid region that may be handled as humid farming land only part of the time, and an adjustment in the cropping systems is necessary to meet this condition. Likewise there is a belt between the dry-farming land and the arid grazing land, in which part of the land may be dry farmed with success only part of the time. And there is a strip around the desert area that may be grazed for a longer or shorter time at irregular intervals, but not throughout the year at any time, and frequently not at all during a given year.

These areas of variable productivity cause much trouble when an attempt is made to show upon the map the boundaries of each kind of land, because the boundary is a zone and not a line. These transition areas will not continuously produce when operated under the more complex type of organization to which they are occasionally adapted; hence they must be operated all the time under a lower, but safe type, and the system of management made flexible enough to accommodate itself to the periods of more than the assured production.

The determining natural conditions are not the average climatic conditions. They are the absolute minima, and the relative frequency with which these minima may be expected to occur. We do not need to be told that citrus fruits can not be grown with profit in a region where the temperature goes to zero for a longer or shorter time one year in five, no matter what it may do the other four years; but it seems to be necessary to demonstrate by trial and failure that

[7] The bracketed figures used throughout this bulletin refer to the publications listed in the bibliography on pages 68 et seq.

crop farming can not be made to support families on land wh periods of drought lasting one, two, three, and even four or five s sons in succession are known to occur with more or less regularit periods of drought so severe that no known cultivated plants can expected to endure them and produce a crop.

The approximate geographical distribution of the lands of e class is shown in the accompanying diagrammatic map (fig. 1).

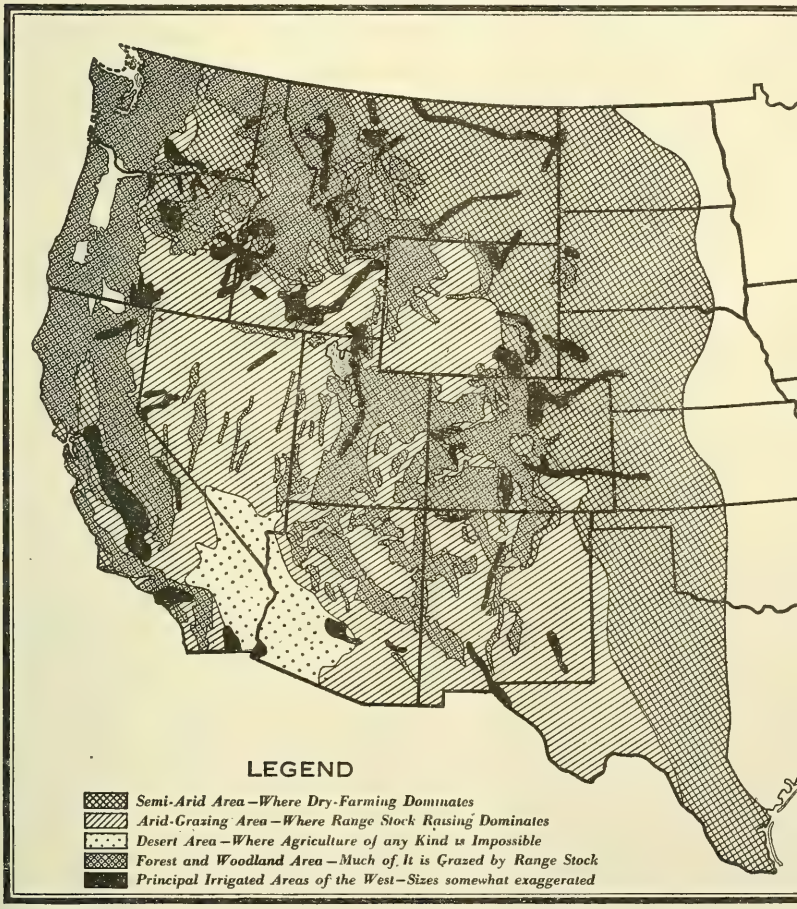

FIG. 1.—Diagrammatic map of the western half of the United States, showing roughly the geogra distribution of the different classes of land as determined by the dominant agricultural use.

no place are the boundaries between areas of the different classes well defined as the lines on the map would suggest. Many sm areas of irrigated or dry-farming land occur in the forest and wo land area, and some occur in the arid grazing area. Likewise in semiarid area there are many places, usually of relatively small si where the land can be used only for grazing. Irrigable land is, course, always capable of intensive cultivation and occurs where

irrigation water may be had. It is believed that much of the great plains region in eastern Montana and Wyoming, shown here as dominantly dry-farming land, will ultimately prove to be arid grazing land.

Definite data as to the area of each class of land to be found in the western United States are not available, but there are estimates and in some cases exact figures from which an approximation may be reached.[8] Using the more reliable of these figures and assuming (1) that the humid crop lands west of the Sierras (outside the National Forests) amount to as much as 20 millions of acres (which is certainly ample) and (2) that there is at least as much arid grazing land in these 11 States as there is semiarid crop land (which is certainly an estimate in favor of the dry-farming land), the following results are obtained:

Classification of land in the 11 Western States.

Class of land.	Acres.	Per cent.	Class of land.	Acres.	Per cent.
Humid crop land	20,000,000	2.67	Forest and woodland	128,000,000	17.09
Irrigable crop land	41,000,000	5.47	Desert land	40,000,000	5.35
Semiarid crop land	260,000,000	34.71			
Arid grazing land	260,000,000	34.71	Total	749,000,000	100.00

[8] Below are presented the data relative to the various classes of lands in the 11 Western States, showing approximate area of each kind, in nearest whole number of millions of acres.

States.	Total land area.	Area of national forests.[1]	Desert area.[2]	Area possible of irrigation.		Area for which water is available.		
				Fortier.[3]	Newell.[4]	As shown by United States reclamation projects, 1918.[5]	Reported by Census for 1910.[6]	Total area in all projects, Census 1910.[7]
Arizona	73	11	10	1	2	0.25	0.39	0.94
California	100	19	20	10	17	.05	3.62	5.94
Colorado	66	13	.....	3	8	.14	3.99	5.92
Idaho	54	18	.....	5	5	.55	2.39	3.59
Montana	93	16	.....	6	11	.16	2.21	3.52
Nevada	70	5	10	2	2	.07	.84	1.23
New Mexico	78	8	.....	2	4	.12	.64	1.10
Oregon	61	13	.....	3	3	.07	.83	2.53
Utah	53	7	.....	2	4	.05	1.25	1.95
Washington	43	10	.....	1	3	.14	.47	.82
Wyoming	62	8	.....	6	9	.13	1.64	2.22
Total	749	128	40	41	68	1.73	19.33	31.11

[1] United States Forester's Annual Report for June 30, 1919. This includes most of the forest and woodland area. State and private holdings are not included in these figures; they amount to several millions of acres.

[2] Rough estimate, based mainly upon the area receiving less than 5 inches average annual rainfall. The area is certainly more than 25 and less than 50 millions of acres in extent.

[3] Fortier, Samuel, et al. National Conservation Commission's Report. Senate Doc. 676, 60th Congress, 2d session, 1909. Vol. 2, p. 67.

[4] Newell, F. H. Irrigation, 1906. These figures assume complete conservation and use of all water resources of each State.

[5] Annual Report Reclamation Service for 1918. Figures show amount of water available for irrigation under United States reclamation projects, not all of which was used.

[6] Statistical Abstract, 13th Census Report. Total area for which water was available in 1910. These figures have doubtless been increased somewhat in the last decade, but the new data are not yet available.

[7] Same. Total area included in projects of all kinds in these States in 1910. In addition, there was in Kansas, Nebraska, North Dakota, Oklahoma, South Dakota, and Texas water for 1.06 millions of acres and 1.84 millions of acres of land in projects already in operation.

Since nearly all of the forest and woodland is operated as arid grazing land, it follows that over half of the area of the 11 Western States is used as arid grazing land and must continue to be so used. Practically all the Government land remaining unreserved is arid grazing land and lies scattered in smaller or larger parcels among lands of other tenure in all of these States. Hence the conclusion is reached that the land policy under which the disposal of these lands is made is of great importance to one of the principal industries, occupying about half the area in the western half of the country, and employing many people.

SOME FACTORS CONTROLLING STOCK RAISING ON ARID GRAZING LANDS.

In the business of raising stock on the arid grazing lands, practices which may be adopted are automatically limited by (1) physical or natural factors, like climate, soil, topography, etc., (2) the resultant forage crop, and (3) social and economic conditions, such as the laws and customs which determine the method of using the land, the marketing conditions, the methods of financing the business.

THE NATURAL CONDITIONS.

The natural conditions governing the stock-raising industry are those which determine the quantity and kind of feed that may be produced and the time at which it may or must be used.

The quantity of feed produced per acre in any part of the arid grazing region is usually small, much smaller than that grown on an equal area of cultivated land. Hence the area of land necessary to produce sufficient feed for an animal for one year is always large as compared with the area required to produce feed for an animal of the same kind on a farm. Rarely less than 7 to 10 acres and often more than 50 acres are required to support a mature cow, or equivalent live stock, for a year. For the southwestern states (not including the desert area) the average is approximately 30 acres per cow.

This region receives relatively little precipitation, there are a large number of clear days during the year, and ordinarily a very dry atmosphere. The plants are subjected to strong light, high daily temperatures, sudden and large changes in temperature, and a wide annual range of temperature, as well as a limited supply of moisture. The different adjustments of these factors of moisture, heat, and light, modified to a greater or less degree by the soil and topography, determine the area over which each kind of plant may grow. The combination of plants growing over an area forms the plant association for that area, and the plant association determines in a broad way the grazing capacity for live stock.

Plant and animal competition.—In any plant association there are always certain plants which, after a long enough period of adjustment, dominate all others and occupy most of the space. These are the characteristic plants of the association and their names are generally used to name the association. Sometimes these dominant species are good forage plants and sometimes they are not. Frequently the dominance of certain plants is due to some other factor than the climatic ones. A good example of this is shown in certain of the plains or prairie regions that formerly were covered with tall grasses but became brush-covered after stock were introduced. Before live stock were brought in, the grass was frequently burned over and all shrubs were killed to the ground. Grasses recover quickly from such burning while shrubs grow more slowly, and are only able to get well started by the time another fire occurs. When grazing animals are introduced and they eat the grass, there is nothing left to burn, and the shrubs reach maturity, changing the whole appearance of the region and often modifying its grazing capacity.

The introduction of grazing animals on any plant association also tends at once to change the relationships existing among the different plants of the association, because the animals do not graze equally all the plants of the association. They always select the plants they like best and eat them first. Thus there is a strong tendency for the plant that is the most palatable feed on the range to be exterminated by the animals. Especially is this the case if the range is too heavily stocked.

The plants of an association also compete among themselves for place. Hence when certain plants, that ordinarily dominate, are eaten, subordinate and usually less palatable members of the association take a higher place in the association than they normally hold. If this overloading of the range is carried to excess for some time, unpalatable weeds occupy the range. It is thus possible for any one who is conversant with the normal plant associations of a region to tell just about how badly and how long a particular range has been overstocked by observing what plants that should be present are lacking and how subordinate ones in the association have increased in importance. In extreme cases of overstocking the edible plants are practically driven out and the soil is occupied by weeds that the grazing animals never eat. A striking case of this kind is seen where the snakeweed (*Gutierrezia* spp.) has completely occupied the short-grass land.

Soil moisture and erosion.—When grazing animals reduce the total amount of vegetation on the area that they graze to such a degree as to increase the rate at which the rain water runs off, two things

have been done which tend to lower the productivity of the area. One effect is a reduction in the total amount of water that enters the soil, with a lessening of the amount available to the growing plants. The amount of feed that plants produce varies almost directly as the available water, up to the optimum amount. Therefore loss of the water means loss of feed on any arid land, because the water supply on such land is always less than might be utilized.

Another effect of the removal of the grass is an increase in the erosion produced by the water that runs off [83][9]. Nothing protects a soil from erosion so well as a thick sod of grass. Any practice which retards the rate of flow of the water reduces its erosive power many fold. All erosion takes away the finer soil and leaves a surface upon which the desirable plants will not readily grow. The process is cumulative and is often carried so far that nothing but an entirely new plant association can occupy the land and the land lies bare and unproductive for a longer or shorter period while the new association is coming in and getting adjusted. This new association nearly always starts as a scattering growth of aggressive and often unpalatable weeds.

It is very hard to maintain a balance between the maximum production of the better forage plants and the maximum number of animals that can be fed upon the area [41]; it is practically impossible to do so upon an open range, where possession is maintained only by having the land overstocked all the time.

Poisonous plants.—Certain of the plants on the ranges are poisonous to stock. The natural tendency of the animals to leave such plants alone because they are usually not palatable tends to favor them in their competition with more valuable plants, with the final result that the poisonous plants tend to increase in quantity as time goes on. Under certain circumstances poisonous plants are eaten by the animals (usually for lack of better feed) and serious losses are suffered. (See bibliography, section 9).

Wild animals.—Besides the domestic stock on a range there are always wild animals, some of which will attack the domestic stock. The extinction of these predatory animals is always an important matter in the range stock business, but when accomplished, it has a reaction which is not altogether desirable. Other wild animals, like prairie dogs and rabbits, that are normally the food of the coyotes, wolves, etc., reproduce rapidly whenever their natural enemies are removed and then they must themselves be removed or they eat up the feed that is needed for the stock. Hence there is a close relationship between the stockman's business and the work of the U. S.

[9] The transporting power of flowing water varies as the sixth power of its velocity. Le Conte, Elements of Geology, 5th ed., p. 20, 1903.

Bureau of Biological Survey in the extermination of predatory and other animals.

Watering places.—A very important controlling factor in the range-grazing industry is the available supply of stock water [60]. Throughout the arid grazing region, watering places are few in number and widely and unevenly scattered. They are frequently hard to develop and expensive, both in first cost and in maintenance. Yet because the business can not be carried on without them, much money and effort have been expended in their development and in attempts to get them properly distributed over the range.

Springs and streams (which are very rare) must be protected; reservoirs must be constructed; wells that are often several hundred feet deep must be drilled and expensive pumping machinery installed and maintained; pipe lines miles in length are often necessary. In all cases the watering place must be so arranged that the animals can get to the water easily, and at the same time the source must be protected. Reservoirs or tanks must be constructed to hold a reserve supply to tide over a breakdown in the mechanical equipment. These difficulties have been more and more effectively overcome as the industry has developed, but the investments in these watering places often represent a large part of the capital that stockmen have put into their business.

Miscellaneous factors.—The low productivity of the land makes imperative the use of a large area as a producing unit. This size factor introduces difficulties of transportation and communication that can be effectively overcome only by relatively large items of expense or capitalization or both.

A very important fact, often overlooked when estimates are being made of the area of arid grazing land necessary to support a family, is that the stock ranch furnishes very little food for the family. In this respect it is like a mine or manufacturing business instead of like a farm. Its product must all be sold and all the provisions for the ranch family must be bought.

If a stockman has children to be educated, the only way it can be done is to send them to town or hire a private instructor. One method entails the maintenance of a house in town, the other the cost of a private school. In either case the business must carry these added expenses and must produce a correspondingly larger cash income. Hence the stock ranch must produce a much larger net income than a farm which gives the same standard of living, and the income is directly dependent upon the size of the ranch.

THE RESULTANT FORAGE CROP.

Since the effects of all the physical factors working together with varying intensity are exceedingly variable over the arid grazing area, there has resulted a set of plant associations having different grazing capacities and adapted to different types of business. (See bibliography, sections 6 and 7.) Some of these areas produce winter feed only, some produce summer feed only, and some produce feed that may be used as a summer or winter or year-long range. The adjustment essential to making the best possible uses of these differing areas is a very complex problem, yet it must be solved and the solution must be upon broad lines. As an example of the resultant condition that exists in a part of the area involved, the following discussion of the main forage types in Arizona and New Mexico is presented. An analogous condition exists in any part of the arid grazing region.

An attempt is made in figure 2 to give a picture of the geographical distribution of the principal range forage plant associations found in the States of Arizona and New Mexico.[10]

This picture is drawn on broad lines and is a generalization. The boundary lines shown are only such approximations as can be made from the data available and the personal knowledge of the investigators. In fact, there are no hard and fast lines marking the boundaries of these plant associations as shown on the map, and there are frequently greater variations in grazing capacity within the limits of what are here mapped as single associations and credited with a uniform grazing capacity than the difference between the average grazing capacities of two adjacent associations. Yet the map serves to visualize the conditions that exist as well as the problem that must be solved in order that the lands may be properly utilized.

The different areas shown are occupied by plant associations that may be easily recognized by some characteristic, well-known plants. The groups are not uniform throughout their separate distribution areas, but the annual supply of forage produced by each association is fairly constant, this supply being affected only by seasonal climatic changes, more especially by the precipitation. Each range forage plant association as here conceived and presented furnishes the forage upon which the live-stock business must depend and has a fairly constant value and certain tolerably definite restrictions as to use.

In naming these associations each has been called by the name of the most characteristic and easily recognized plant, though this has led to the use of names of plants that are not themselves forage plants. For convenience of reference a number has been assigned to each association, commencing at the lowest levels on the desert.

A table of estimates of areas of each forage type in the Atlantic & Pacific Railroad land grant area, in the State, and in the two States combined, with percentages of total area in each is also given. (See Tables 1 and 2.)

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[10] Taken from a report to the Secretary of Agriculture upon "An Investigation of Conditions of the Grazing Land Lying Within the Limits of the Atlantic and Pacific Railroad Land Grant." By Wooton and Hill, 1919. In compiling the map, the United States Geological Survey topographic sheets for Arizona and New Mexico were used as base maps, and published and unpublished data of this division of the service were also used. The published and unpublished life-zone maps of these two States prepared by the Bureau of the Biological Survey were freely used, as were data on plant distribution taken from Forest Service records. Plant distribution maps by Shantz and Zon and by Shreve were consulted and used whenever they were of service. The authors have had field experience in the region extending over many years and their field notes were used.

TABLE 1.—*Characteristics of the principal forage type plant associations in Arizona and New Mexico.*

Data.	Forage type No. 1, desert shrubs and annuals.	Forage type No. 2, semi-desert grassland.	Forage type No. 3, short-grass land.	Forage type No. 4, woodland.	Forage type No. 5, yellow-pine forest.	Forage type No. 6, spruce-fir forest.[3]
Characteristic plants easily recognized.	Palo verde. Palo duro. Creosote bush. Mesquite. Saguaro. Chollas. Other cacti.	Mesquite. Catclaw. Desert willow. Mormon tea. Salt bushes. Yuccas. Some cacti. Certain scrub oaks.	Short grass; no trees. Grama and buffalo grass. Rabbit brush. Small sagebrush. Apache plume. Snakeweed. Summer weeds.	Pinyons Junipers. Evergreen oaks. Mountain mahogany. Black sage. Numerous shrubs.	Western yellow pine. Gambell's oak. Wild cherry. Gooseberries. Currants. Many other shrubs. Many flowering weeds.	Douglas spruce. Colorado blue spruce. Engelmann spruce. Balsam. Aspen. Tall grasses.
Principal forage plants	Alfilerilla. Indian wheat. Annual grasses. Borages. Many other annuals. Browse on shrubs mentioned above.	Black gramas. Tobosa grass. Galleta grass. Needle grasses. Burro grass. Dropseed grasses. Salt bushes. Browse on shrub; weeds.	Blue grama. Buffalo grass, locally. Sagebrush. White sage. Some dropseed grasses. Summer weeds.	Blue grama. Sagebrush. Certain bunch grasses. Browse from oaks and shrubs. Summer weeds.	Blue grama. Colorado blue stem. Arizona fescue. Wheat grasses. Oak and other browse. Many shrubs. Many herbs.	Many tall grasses. Fescues. Poas. Red top. Timothy. Sedges. Many shrubs and herbaceous plants.
Extreme altitude,[1] range (feet above sea level).	500 to 2,000 feet	2,000 to 5,000 feet	5,000 to 7,500 or even 8,000 ft. in places, mostly between 5,000 and 6,000 ft.	5,500 to 7,500 feet, mostly 5,500 to 6,500 feet.	6,500 to 8,500 feet, mostly below 8,000 feet.	8,000 feet to timber line.
Precipitation (in inches):						
Average annual	5 to 6 inches	About 9 to 10 inches	About 11 to 12 inches	About 15 to 16 inches	About 20 inches	Probably 25 to 30 in.
Average seasonal [2]	1.5 to 2 inches	About 5 inches	About 6 inches	About 8 inches	About 8 inches	Probably 10 to 12 in.
Season forage is available.	Late winter and spring occasionally.	Yearlong	Yearlong	Yearlong	Mostly summer; yearlong in places.	Short summer season.
Kind of stock to which it is best suited.	Sheep	Cattle; breeding ranges	Cattle or sheep	Cattle or sheep	Cattle or sheep	Mostly sheep; cattle some places.
Grazing capacity (yearlong for 1 cow).	Average not better than 100 acres.	35 to 40 acres	20 to 30 acres	20 to 30 acres	25 to 27 acres	No figures available, but high for short season.
Character of stock water	None permanent; small amount in temporary pools.	Mostly wells and earth reservoirs.	Springs, wells, and reservoirs.	Springs, a few intermittent streams, reservoirs, and wells.	Springs, streams, reservoirs, a few wells.	Springs and streams mostly.
Character of utilization at present.	Not over one-half the area now utilized by sheep; a few cattle on it in places, but have to be taken off part of year.	All in use; mostly occupied by cattle, sheep from desert area forced into it; mostly very poor sheep range.	All in use by cattle and sheep, mostly as yearlong range.	All in use by cattle and sheep, mostly as yearlong range, sometimes as winter range only.	All in use, mostly as summer range for sheep and cattle, sometimes as yearlong for cattle.	Summer range only; mostly used for sheep, occasionally for cattle.
Growing season	From Dec. 1 to May 15	Shrubs and most other perennials in spring; grasses and herbaceous plants, July to October.			Shrubs in spring, mostly a summer growth.	Late spring and summer.

[1] Altitude ranges seem to overlap because the extremes of distribution are given. These are affected by slope, exposure, and other factors, so that the belt or zone of a given association of plants is higher on one side of a mountain than on the other.
[2] Seasonal precipitation refers to the amount falling between May 1 and Sept. 30. This period is not the growing season for the desert area.
[3] The very small area of mountain peaks above timber line is included in this division for convenience.

TABLE 2.—*Estimated area and percentage distribution of each forage type within the limits of the Atlantic & Pacific Railway grant and within the two States.*

Forage type.	No. 1. Desert shrubs and annuals.	No. 2. Semidesert grass land.	No. 3. Short-grass land.	No. 4. Woodland.	No. 5. Yellow-pine forest.	No. 6. Spruce-fir forest.	Total.
IN ARIZONA.							
In the grant area:							
Acres	2,081,687	9,048,223	2,790,835	6,559,718	2,421,320	51,011	22,952,794
Per cent of total	9.1	39.4	12.2	28.6	10.5	0.2	100
In the State:							
Acres	17,408,378	23,963,834	9,031,961	15,878,771	5,972,749	582,707	72,838,400
Per cent of total	23.9	32.9	12.4	21.8	8.2	0.8	100
IN NEW MEXICO.							
In the grant area:							
Acres	.....	901,555	3,912,584	2,765,676	1,865,180	183,260	9,628,255
Per cent of total	.....	9.4	40.7	28.7	19.4	1.8	100
In the State:							
Acres	.....	17,483,628	30,655,151	15,209,972	12,152,298	2,900,871	78,401,920
Per cent of total	.....	22.3	39.1	19.4	15.5	3.7	100
IN THE WHOLE AREA.							
In the grant area:							
Acres	2,081,687	9,949,755	6,703,419	9,325,394	4,286,500	234,271	32,581,049
Per cent of total	6.4	30.5	20.6	28.6	13.2	0.7	100
In the two States:							
Acres	17,408,378	41,447,462	39,687,112	31,088,743	18,125,047	3,483,578	151,240,320
Per cent of total	11.5	27.4	26.2	20.6	12.0	2.3	100

Estimates as to the total area of land in New Mexico which may be dry farmed have run as high as fifteen millions of acres, but experience has shown that this is considerably exaggerated, since much of the land which was assumed to be proved dry farming land has since been abandoned on account of the drouths. No complete estimate for Arizona is available, the tentative figures by Clothier and McOmie ranging from one-half to one million acres for the State.

Estimates as to the amount of irrigable land in each State are given in footnote 2, on page 8. The irrigable areas for these two States and for the land grant area are included (without being indicated) in the figures given above because it is not possible to work out the details of their distribution with the information now available.

THE LAND TENURE.

The discussion of but one of the social and economic factors which affect the grazing industry is here proposed; i. e., our Government land policy [11].

There are two ways in which the tenure of the land must be considered, and they are here referred to as the "legal status" of the land and its "use control." Although ordinarily legal tenure gives use control, subject to the sovereign powers of the State and Federal Governments, the nature of the occupancy of some of these arid

lands does not permit full control of the use, for reasons already set forth [12].

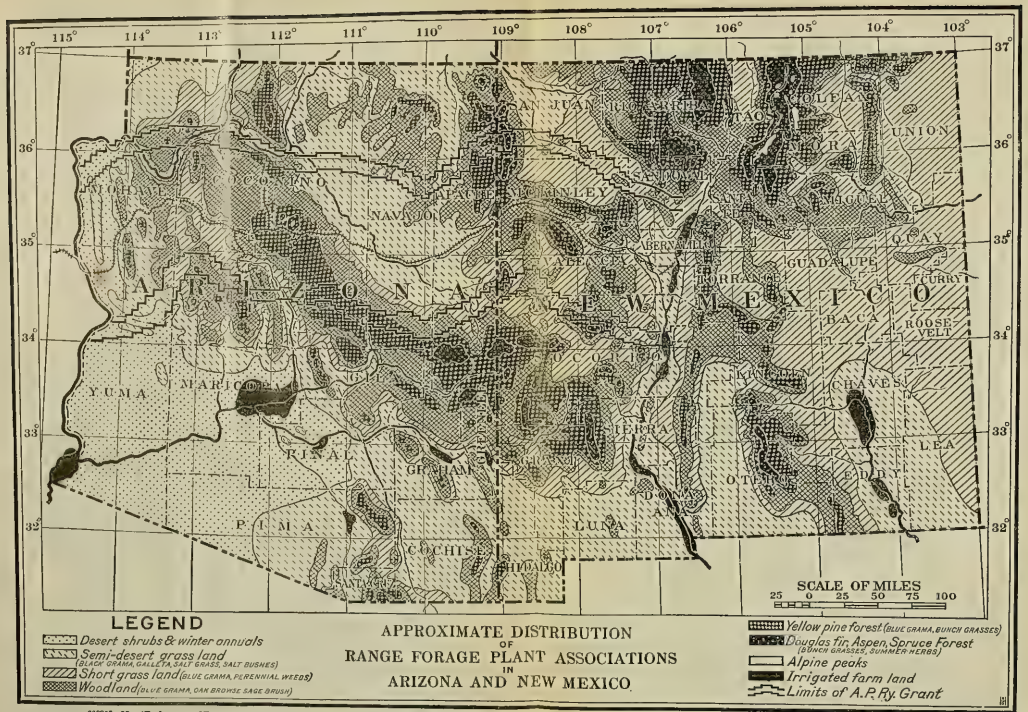
The legal status of the lands.—The present tenure of the land [2] is to be explained in terms of the history of its acquisition and the methods of disposal which have been in use by our Government [5]. The acquisition concerns us little here, but the methods of disposal explain very clearly the reasons for the present status. (See bibliography, section 1.)

Large areas of land in certain of the Southwestern States that were originally settled by colonists from Mexico are held under titles conferred by the Government of the United States in accordance with treaty stipulations. In consequence there are to be found in this region many large areas of land lying in solid bodies, often amounting to many thousands of acres, that may be handled as units. Most of such land has been used as open range and much of it is still so used because the title rests in communities or groups of numerous heirs. Certain individuals, often part owners of the land, recognizing the advantages to be gained by proper management, have recently obtained control, in one way or another, of several of these grants and have fenced them. It is only a question of time until they will all be so managed. (See fig. 3.)

Immense areas of the land of the Western States have been set aside as reservations for the use of various Indian tribes under the direction of the Department of the Interior. (See fig. 4.) Changes in the areas of these reservations occasionally occur; sometimes they are extensions, but more frequently reductions, or the land may be allotted to individual members of the tribe. Extensions of area have led to the issuance of lieu land scrip for certain lands that have been surrendered for addition to the reservations (See p. 65.) Some of the Indians do not live on their reservations, or do not have enough stock to use all the forage. Under such conditions the Indian agents have rented grazing land or privileges to stockmen of the region—a practice which benefits both the stockmen and the Indians.

As early as 1823, Congress established the policy of granting areas of public lands to separate States and Territories to encourage the construction of canals, river improvements, and wagon roads. Beginning about 1850, grants of a similar character were made, first to the States, and later to the railroads, through certain thinly populated sections of the West. This policy was continued until 1871, and many millions of acres of public land were transferred in this way to railroad corporations [6]. (See p. 65.)

The ordinary method of making these grants was to give certain sections out of every township (usually the odd-numbered ones) within a belt of a specified number of miles on each side of the rail-



APPROXIMATE DISTRIBUTION OF RANGE FORAGE PLANT ASSOCIATIONS IN ARIZONA AND NEW MEXICO

Fig. 2.—For detailed explanation of this map see pages 13 to 15.

road, with an "indemnity" strip of specified width outside of this, from which selections could be made equal to the area of land already appropriated within the grant strip which would have come to the grantee under the terms of the act. (See fig. 2.) These lands were selected according to the terms of the act, but not all have yet been patented. On unsurveyed land it is impossible to issue patent and much of the land selected is unsurveyed at present. Considerable areas of land originally granted were forfeited to the Government because of failure to carry out the conditions of the grant. (See p. 65.)

The original grantees have handled their lands in various ways. Much of such land has been sold outright to all sorts of purchasers, e. g., other railroads, land companies, lumber companies, stockmen, etc. Considerable areas are still the property of the railroads and are leased to various kinds of users. The right transferred by the railroad company is only that which they shall themselves receive after all Government proceedings relating thereto are complete. Under certain conditions parts of these lands have been returned to the Federal Government, and lieu land scrip, which may be placed upon other Government land that is open for entry, has been issued in exchange for it [7]. (See p. 65.)

The effect of the railroad land-grant legislation is to produce a checker-board arrangement of the land tenure in each township, the odd-numbered sections belonging, either tentatively (pending survey) or actually (patent having issued), to the railroad company or its assigns, and the even-numbered sections belonging to some other owner or to the National Government (see figs. 3, 4, and 5).

Certain sections out of each township, particularly in the West, were given at one time or another to a number of the States. These lands are managed by the States for the benefit of their public schools, and are usually referred to as State school lands. In New Mexico and Arizona, sections 16, 36, 2, and 32 are the school sections, unless they were appropriated before the laws granting them were made, under which circumstances the State received the right to make lieu selections (see figs. 3, 4, and 5).

At various times, under one act or another, relatively large grants of public land have been made to the different States, the proceeds from the lease or sale of which are used for the support of the higher educational and other institutions of the State. The administration of these lands and the school lands is usually in charge of a State land commissioner under laws passed by the State legislatures, and the policies are different in different States. In general, it is possible to lease any of such lands for longer or shorter periods, and some of them may be bought outright[11] (see figs. 3, 4, and 5).

[11] For details see the annual reports of the State land commissioners of the different States.

Beginning in 1891 there was inaugurated the policy of setting aside forested lands which ultimately became what are now called National Forests. The areas so withdrawn have been increased until now they amount to over 150 million acres. The use of these lands as a source of timber and timber products is of primary importance; of next importance is the proper control of watersheds so as to utilize irrigation and other waters in the best way; the control of the grazing within the forest ordinarily receives consideration after provision has been made for the other two uses. From the beginning down to the present the control of the grazing privileges in these National Forests has been one of the most difficult problems. Its solution has resulted in a system of permits to graze stock on specified areas for longer or shorter periods upon payment of certain fees, the granting of the permits being dependent upon various degrees of equity among applicants [87]. This system of control has been very beneficial to the forage crop within the controlled areas and consequently to the business affected thereby. It is generally referred to as the permit system of grazing control and it has certain advantages over other systems that have been tried, though, like every other system, it has disadvantages under certain conditions.

Private holdings of large size lying within the national forests, especially those like the railroad land grant sections, are to a considerable extent administered by the forest officials, under agreement between the owners and the Forest Service, with a pro rata division of benefits received. Exchanges for the purpose of consolidating the forested lands have occurred to some extent under various special acts authorizing this practice, which, although it has not always worked out satisfactorily, is of unquestionable value in certain selected places and under proper restriction. (See p. 65.)

Besides the national forests, certain other areas have been set aside as national monuments, national parks, military and naval reservations, etc., but the amount of such lands is relatively very small.

The recognized methods by which land may pass from the Government to a private individual are sale and homesteading [1]. Only very small areas may be sold to one buyer. Any of the surveyed, unreserved, unappropriated, non-mineral public land, may be taken under the homestead laws in certain limited quantities by anyone legally qualified to make homestead entry [3]. (See p. 65.)

The original homestead law (passed in 1862) allows an entryman to secure title to 160 acres. The great bulk of the good agricultural land was homesteaded under this law half a century ago. Practically all of the land that has been homesteaded within the last 15 or 20 years, until quite recently, is either dry farming land or land for which irrigation water has been found.

The enlarged Homestead Act was passed in 1909, allowing an entryman to obtain 320 acres of a certain kind of land as a homestead. Much of the land that was originally taken under this law was ultimately abandoned because it was too dry for dry farming; some of the holdings that were patented have been consolidated into larger blocks and are now mostly used as grazing land, small areas being cropped wherever and whenever practicable.

The Kinkaid Act, increasing the area obtainable in certain parts of Nebraska to 640 acreas, has been used in much the same way.

In December, 1916, the grazing homestead act was passed, allowing an entryman to take up 640 acres of land that is principally valuable for grazing. In its interpretations of this law, the land classification division of the United States Geological Survey, which has charge of the classification of the lands to which this law might be applied, recognized certain upper and lower limits of productivity of the land that might be taken under this act. Recent decisions have established a still lower limit of productivity which shall be recognized as the minimum production of land of this class. Much of the remaining land that is open for entry has already been classified as belonging to the class which may be obtained under the enlarged homestead act. Land which may be taken under the grazing homestead act is usually not classified until an application is made for a specified area, and the "application" is not allowed as an "entry" until a favorable classification is reported. The settler acquires no right to the land by going on it before his "entry" is recorded at the district land office. Since the entryman on an enlarged homestead may ask for an increase of his holding from 320 acres to 640 acres under the grazing homestead act, it is now customary to "enter" an enlarged homestead and "apply for" an additional 320 acres as a grazing homestead. This permits the settler to commence work on the place without loss of time.

The Kinkaid, the enlarged homestead, and the grazing homestead acts have all been passed in an attempt to provide proper land legislation for the dry lands of the West. Mostly, however, their effect has been to put land out of use for a longer or shorter time, because the areas obtainable under each act were not large enough for the profitable pursuit of the business which could be carried on upon the lands that were still available when the laws were passed. (See "Discussion of consequences," p. 49 et seq.) Notwithstanding what must be said against the working out of the policy which these laws represent, two minor advantageous results must be recognized. Legal tenure to the land is ultimately obtained locally, generally after much waste of labor and wealth; and the forage plants have an opportunity to recover from the effects of previous overstocking. The 320-acre law did help out some men who took up dry farming

land under the 160-acre law and were able to live on it, as did the Kinkaid Act in Nebraska. The grazing homestead act will help an occasional man to consolidate other holdings and make a productive stock ranch.

Under certain conditions an Indian who has not abandoned tribal relations may acquire a tract of land in lieu of his rights to common lands in an Indian reservation, under conditions similar to those of the homestead acts [3] except that the period of occupancy is longer before patent is obtained. Such areas are spoken of as Indian allotments. (See p. 65.) Like the homestead laws, this arrangement is not an unmixed blessing.

Thus the land of the arid grazing region is held as Mexican land grants; Indian reservations; railroad lands patented, lands selected but not patented, or lands the railroad titles to which have been sold to others; State school and institutional lands; national forests, monuments, or reserves; homesteads patented or pending; Indian allotments completed or pending; and Government land open for entry. It is possible, in one way or another, for the stock man to obtain legal control over the use of all of these lands except the Government land that is open for entry. The consequence of the application of these various laws is that the Government land is now so distributed that it is very difficult to find areas of controllable land of more than a very few sections in solid blocks, and that such blocks are usually so irregular in shape that the expense of fencing them is frequently prohibitive, even where watering places happen to be properly located to serve them. All these lands, except Government lands, have some kind of legal status that permits them to be fenced, if, by so doing, public lands be not enclosed. If the fencing of the privately owned lands would in any way interfere with the possibility of any citizen's using the public lands, the fencing must be arranged so as to avoid this difficulty, and frequently it is impossible to do this.

The outstanding feature of the case is that the laws governing the disposal of our public lands, because they do not authorize control of lands that remain in the hands of the Government, automatically prevent owners, lessees, and permittees who have invested large sums of money in their holdings and equities from fencing their holdings or otherwise controlling them in the interest of a more advantageous use. Nor is this all. The consequences to the State and to the nation are, (1) a much lower total production from the whole area, (2) a much lower standard of business organization than is easily possible and highly desirable, (3) a continually diminishing productivity of the lands, and (4) an increasing precariousness in the business, to say nothing of lost taxation and lack of social progress.

The diagrammatic maps (figs. 3, 4, and 5) will give some conception of the complicated condition of tenure that has resulted from the application of these land laws to a particular region. These maps, and the immediately following discussion of the present legal tenure of the land in the Atlantic and Pacific land grant area, are based on data taken from the previously cited report on the condition of grazing land in that area.

In studying the effects of the 1917–18 drought upon the stock-raising industry in Arizona and New Mexico, the present condition of legal tenure of the land of a selected area (the Atlantic and Pacific Railroad Land Grant) was ascertained from the District United States and State Land Offices at Santa Fe, N. Mex., and Phoenix, Ariz. These data were mapped on a large-sized base map and reduced copies of three sections of it are here presented.[12]

In studying these maps it must be remembered that much of the land shown as railroad land has been sold to others, sometimes to large companies who have sold again or now lease it. In a few places large consolidated areas of railroad land are shown. Such places indicate where railroad lieu lands have been selected in such a way as to consolidate an area so that it may be fenced up. In places alternating railroad sections are shown in the national forests. These lands may still belong to the railroad or may have been sold. In many cases they are administered by the United States Forest Service and the owner or lessee gets free permit for the number of animals such an area is able to carry.

Some of the land that lies inside the National Forests, but shown on the map as homestead land, is almost certainly railroad grant land which has been bought by its present owners. In Table 3 such land has been included with the homesteaded land, thereby raising the figures for percentage and total amount of homesteaded land, perhaps considerably above the actual.

Large areas are shown as Indian reservations and Indian allotments. The Navajos, Hopis, Zunis, and the remaining Pueblo tribes live on their reservations, but the Hualapais mostly do not stay on their reservations and the grazing privileges on about two-thirds of it are rented to stockmen.

The State school lands are restricted by law to certain sections in each township or lieu selections when these sections have been disposed of, but the other State lands have frequently been used to consolidate "checkerboard" holdings obtained from the railroad. Any of the State lands can be leased and some of them can be purchased. The government land that is open for entry is shown as white on the maps. The percentage of each kind of tenure within the land-grant strip is shown for each State and for the two States combined, in the table.

The maps and figures show clearly that the stockman's inability to control about one-fourth of the total area within the limits of this land grant determines how a large part of the remainder must be used.

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[12] The condition shown in the maps is about as complex as any that can be found. The checkerboard arrangement of holdings is, of course, the result of the method used in making the land grant to the railroad company and is to be found only in regions where such grants were made.

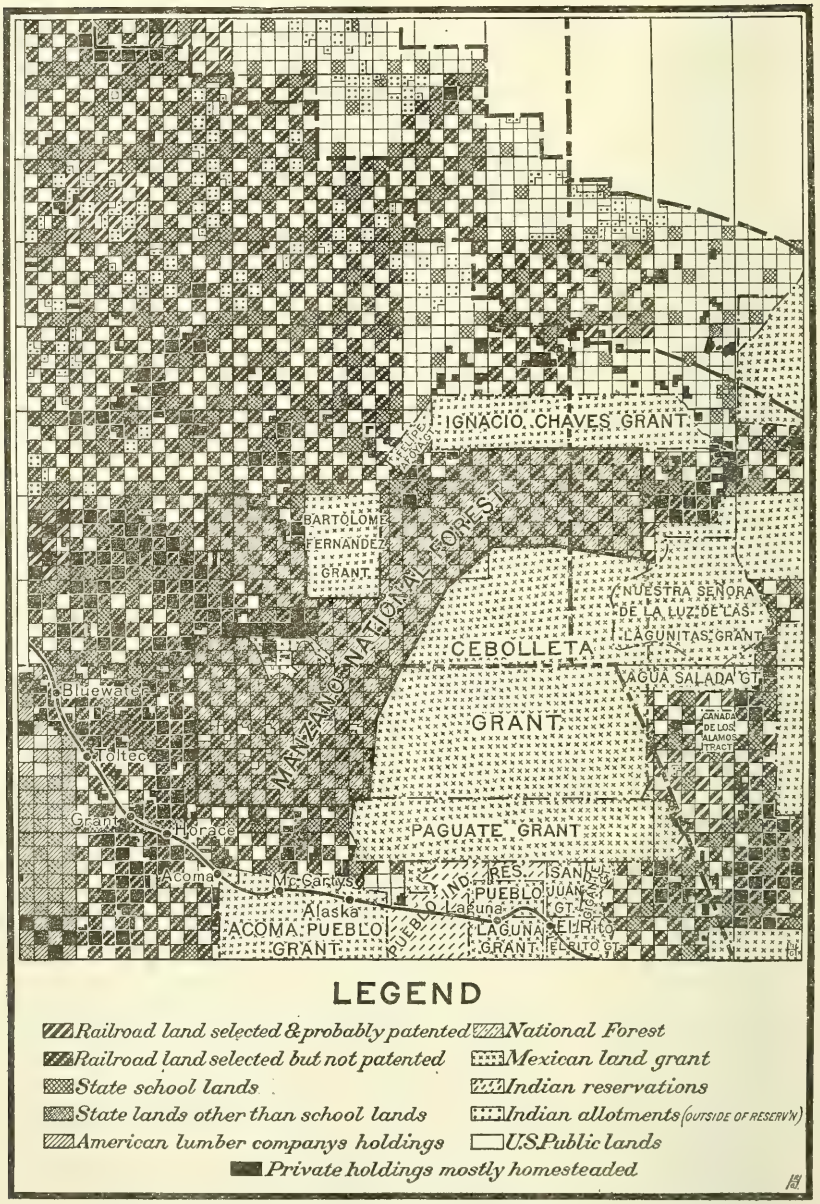

FIG. 3.—Diagrammatic tenure map of an area in northwestern New Mexico.

This portion of the tenure map shows:

1. The characteristics of the Spanish land grants.
2. The effects of a checkerboard arrangement of national forest and railroad grant lands.
3. The effects of the sale of railroad lands to private individuals (black) or corporations (American Lumber Co. holdings).
4. The effect of surrender of railroad lands for lieu land scrip, as shown in the white areas within the primary and secondary grant limits at the upper right-hand corner.

The distribution of the public lands, open for entry, is characteristic for any railroad land-grant area where the land is of low productivity.

Each of the small squares into which the map is divided represents one section of approximately 640 acres.

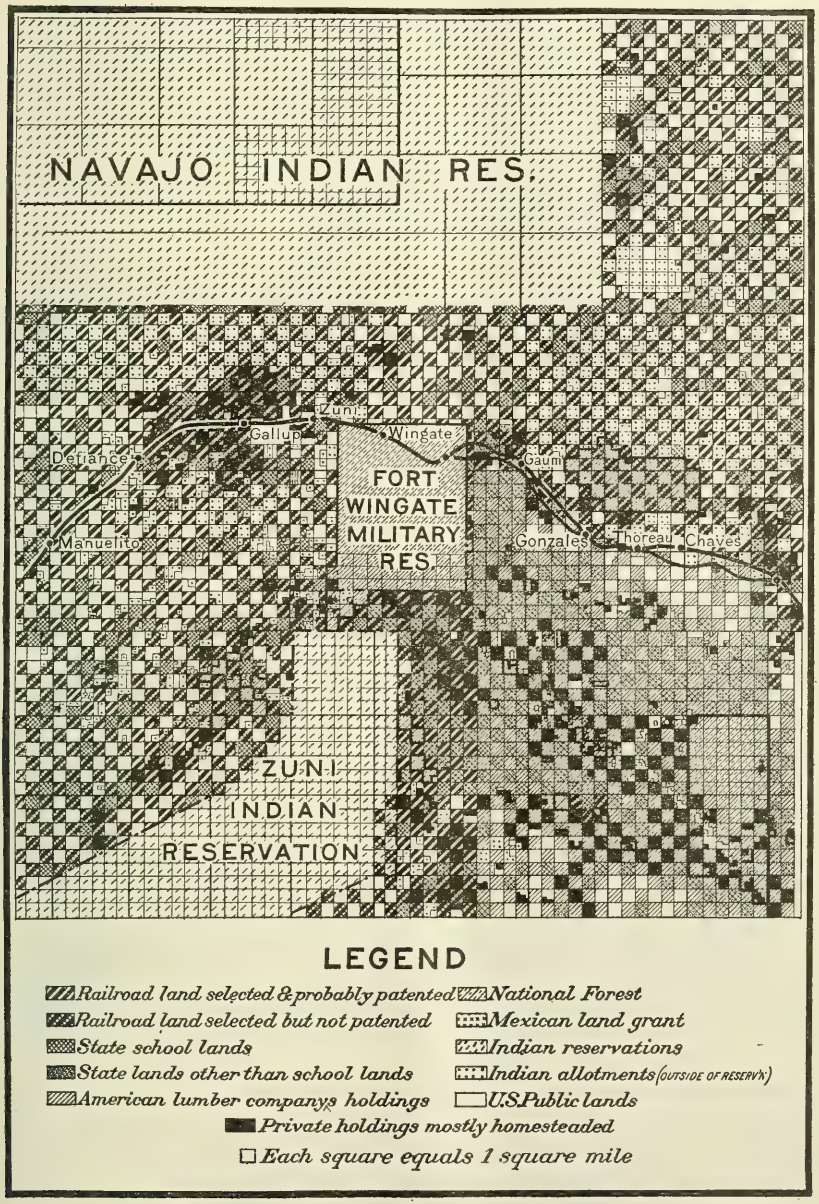

FIG. 4.—Diagrammatic tenure map of an area in northwestern New Mexico.

This portion of the tenure map shows:

1. The characteristic distribution of Indian reservations.
2. The area and distribution of Indian allotments.
3. The effects of the purchase of railroad lands by private individuals and corporations and the selection of the even-numbered sections by the State.

In much of the area the Government land (white) is shown to be that which determines the character of control possible.

Each of the small squares into which the map is divided represents one section of approximately 640 acres.

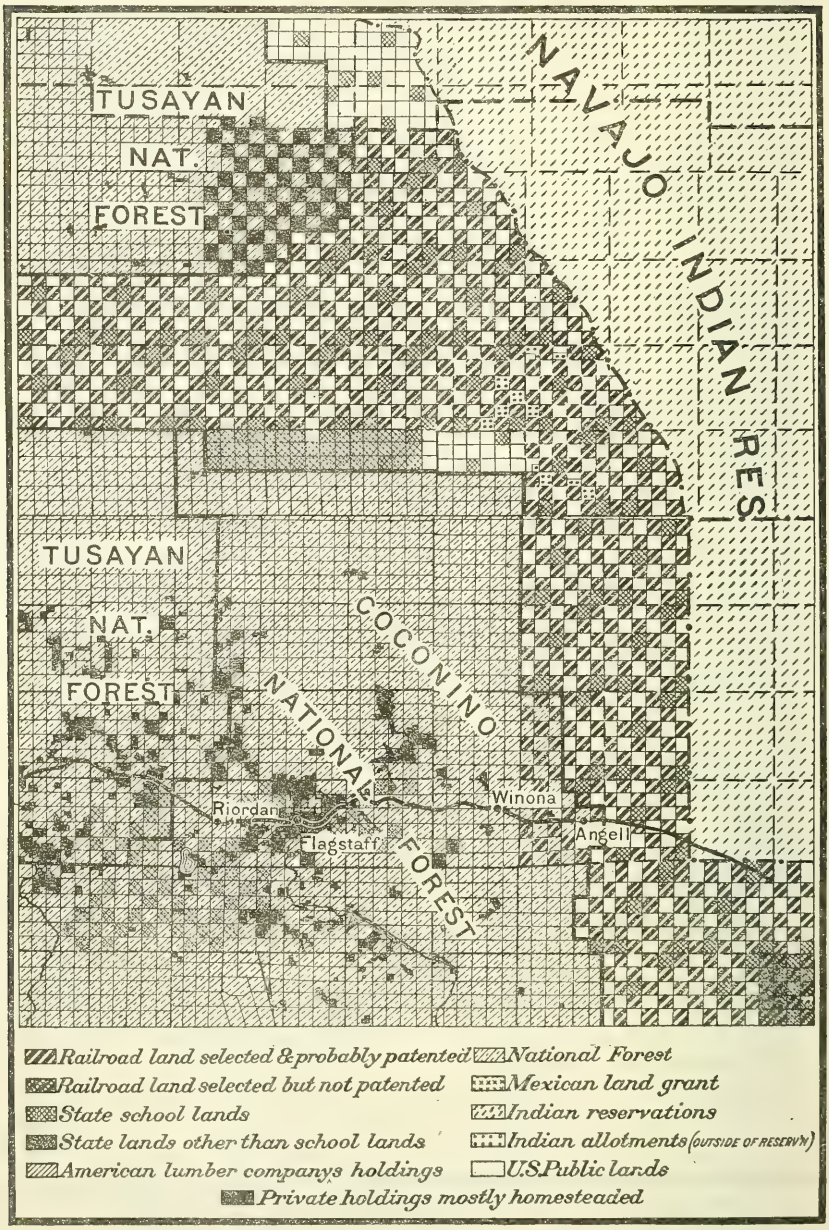

FIG. 5.—Diagrammatic tenure map of an area in central northern Arizona.

This portion of the tenure map shows:

1. Characteristic distribution of agricultural land in a national forest.
2. The effects of the purchase of railroad land inside national forest boundaries.
3. The results of State selections within national forest boundaries.
4. Consolidation obtained by State selections.
5. The typical checkerboard arrangement of railroad lands, State school lands, and Government lands.

Each of the small squares into which the map is divided represents one section of approximately 640 acres.

TABLE 3.—*Approximate subdivision of the lands within the Atlantic and Pacific land-grant boundaries.*

(According to tenure for each State and for the entire grant.)

	Arizona.			New Mexico.			Whole grant.	
	Area.	Percentage of area.		Area.	Percentage of area.		Area.	Percentage of whole grant.
		In State.	In grant.		In State.	In grant.		
Railroad lands:	*Acres.*			*Acres.*			*Acres.*	
Selected and patented	2,321,320	10.3	7.3	2,137,200	23.1	6.7	4,458,520	14.0
Selected, not patented	2,593,620	11.5	8.2	542,550	5.9	1.7	3,138,080	9.9
State school lands	1,478,320	6.6	4.6	523,520	5.7	1.6	2,001,840	6.2
State lands, all other kinds	935,280	4.1	2.9	140,280	1.5	.4	1,075,960	3.3
National forests	3,291,960	14.6	10.4	482,200	5.2	1.5	3,774,160	11.9
American Lumber Co. (originally railroad lands)	.....	.....	.....	254,600	2.7	.2	254,600	.8
Indian reservations	4,532,480	20.1	14.3	1,458,200	15.8	4.6	5,990,480	18.9
Indian allotments (outside reservations)	129,840	.6	.4	338,640	3.7	1.1	468,480	1.5
Mexican land grants	92,640	.4	.3	952,040	10.3	3.0	1,044,630	3.3
Private holdings (mostly homesteads)	952,120	4.2	3.0	448,320	4.8	1.4	1,400,440	4.4
U. S. Government lands	6,221,120	27.6	19.6	1,966,240	21.3	6.2	8,187,360	35.8
Total	22,550,600	100.0	71.0	9,243,800	100.0	29.0	31,794,400	100.0

NOTE.—The figures given here are only approximations. Much of the land has not yet been surveyed and exact figures could not be obtained. The estimate in acreages assumes all sections to contain 640 acres, which, of course, is not exact. The percentages of the different kinds of tenure are doubtless fairly accurate, at least to units place.

The present use-control of the land.—The problem of how to control the range in separate units of such size as to make the business of raising stock profitable has been before all stockmen ever since the ranges commenced to be crowded, even in local areas. In earlier days there was an abundance of feed for the animals of those who had the courage and skill to enter the business, but in a relatively short time the excess feed was all used in the more favorably located places, and the contest for place began.

The necessity for individual control has kept pace with the growing specialization of the business, and rising prices have made profitable greater and greater expenditures for rights or privileges in a range. The struggle has gone on from one degree of intensity to another until at present many individuals and firms have invested large sums of money in permanent improvements, such as wells, reservoirs, pipe lines, troughs, corrals, fences, houses, etc., as well as in the purchase or lease of part of the lands they are using. Whenever it has been possible, such men have got legal control of all their land and fenced it. In practically all cases the improvements have been protected by some sort of legal control of the land on which they have been made. A few men make their investments as small as possible with the object of making some one else bear their burden of capitalization, and thus take advantage of the open range condition.

The existing system of management in this industry is determined in many cases by the possible use which may be made of Government land and the legal control of the land upon which stock water occurs.

Ordinarily the land carrying the water is owned by the user, though he may lease it from a railroad company, from the State, an Indian reservation, or other owner. Ownership has sometimes been obtained by homesteading, sometimes by placing lieu land scrip on it. Sometimes the water is covered by a patented mining claim, or, if it is on unsurveyed land, rights may be acquired by a settlement made by a qualified homesteader for the purpose of subsequently making homestead entry after the lands are surveyed, and such rights can be maintained only by substantially continuous occupation and the right to all improvements which he may make or purchase from a former occupant. Sometimes the water is on a mining claim that is not patented, but tenure of the claim is maintained by doing the ordinary assessment work each year.[13]

To-day the open range is held on a tacit agreement among stockmen that the stock water will be used in common, each man developing enough for the number of animals he puts on the range. The feed also must be used in common, since each ranch is bounded only by the imaginary line passing halfway between its watering places and those of the nearest neighbors all around it. Thus feed and water, salt and bulls, must be used in common, and individual control of their businesses is not possible for most of the stockmen of the region.

Notwithstanding the undesirable and irritating conditions that surround the industry, the old policy of "eat out the range and move on" has been discarded forever. The men who now carry on the industry are as permanently located as men in other kinds of business and are anxious to develop it as rapidly as possible if the opportunity is given them. That opportunity can be given only by proper land legislation.

As an indication of what men will do to get control of the ranges they use, some data as to the use-control of the lands inside the Atlantic and Pacific land-grant area are presented.

In the study of grazing lands previously referred to, some data were obtained relative to the actual control of the lands of the region examined.[14] The lands originally granted to the Atlantic & Pacific Railroad Co. have been sold or leased to many companies and individuals. The existing use-control of the region is very largely determined by the present legal tenure of these lands, though the disposition of the State lands of the area is also an important factor. Stockmen have bought or leased large areas of this land in the hope of controlling as nearly as may be all the land they use. A few of the holdings are completely consolidated, under one form of tenure or another, and are partly or all fenced.

The sizes of the range units shown in Table 4 are approximately the amounts of land that individual stockmen use (occasionally in common with others who have little or no equities) by virtue of having bought or leased most or all of the lands of their ranges that could be so obtained. The proportion of each range so held varies from more than half to all of it.

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[13] The minimum amount of development work on the claim required by law to maintain possession.

[14] This information was obtained through the courtesy of the officials of the Santa Fe Railroad Co., St. Louis & San Francisco Railroad Co., Aztec Land and Cattle Co., and numerous individuals.

TABLE 4.—*Number of ranges of indicated sizes and total areas (approximate) which are individually used and to some degree controlled by virtue of equities in that part of each range that may be obtained by purchase or lease from the railroad or other owner.*

Approximate size of area used (acres).	Arizona.		New Mexico.		Total.	
	Number.	Total area so controlled.	Number.	Total area so controlled.	Number.	Area so controlled.
		Acres.		*Acres.*		*Acres.*
10,000 or less	43	126,720	23	121,600	66	248,320
10,001 to 20,000	45	637,200	41	599,040	86	1,236,240
20,001 to 40,000	71	1,748,480	77	1,997,480	148	3,745,960
40,001 to 60,000	28	1,292,160	13	608,640	41	1,900,800
60,001 to 80,000	7	496,000	9	610,560	16	1,106,560
80,001 to 100,000	7	614,400	7	646,400	14	1,260,800
100,001 to 150,000	16	1,872,000	3	368,640	19	2,240,640
150,001 to 200,000	7	1,154,560	4	652,800	11	1,807,360
200,001 to 300,000	2	496,000	.....	.....	2	496,000
300,001 to 400,000	2	693,120	.....	.....	2	693,120
Over 400,000	.....	.....	[a] 1	587,520	[a] 1	587,520
Total	228	9,130,640	178	6,192,680	406	15,323,320
Average size	.....	40,047	.....	34,790	.....	37,742

[a] This area is subleased to a number of small operators.

TABLE 5.—*Data obtained from stockmen using ranges within the limits of the Atlantic & Pacific Railroad land grant* [*12*].

Item.	Cattlemen.			Sheepmen.		
	Average number of acres.		Number of men reporting.	Average number of acres.		Number of men reporting.
Character of tenure:						
Leased railroad lands	23,752		35	23,441		20
Leased school lands	5,409		43	3,444		19
Leased State lands	7,146		24	29,257		7
Owned lands	6,635		39	18,305		21
Approximate size of area used	74,286		62	[a] 73,220		32
	Average number of years.		Number reporting.	Average number of years.		Number reporting.
Period of use	14.4		39	10.3		15
	Average acres per cow.		Number reporting.	Average acres per sheep.		Number reporting.
Estimate of grazing capacity:						
Normal	38		50	11		15
Decrease due to use (estimated average)	5 per cent.		42	5 per cent.		20
Decrease due to current drought (estimated average)	30 per cent.		46	36 per cent.		23
	Total number.	Average number per ranch.	Number reporting.	Total number.	Average number per ranch.	Number reporting.
Number and kinds of watering places:						
Springs	175	6.2	28	18	2.5	8
Streams	10	1.6	6	.....	.....	.....
Reservoirs or tanks	209	6.5	32	133	7.0	19
Wells	87	2.8	30	32	3.5	9

[a] Two very large holdings omitted because definite data were not obtainable.

The table also indicates that the stock ranches of the region mostly contain from one-half to two townships of land, which is probably a fair indication of what stockmen of that region think they need. (See also Table 5.)

SOME CONSEQUENCES OF THE OPEN-RANGE METHOD OF STOCK RAISING.

An open-range system of management of the arid grazing lands of the West has been inevitable, in view of the natural conditions of the region and the Government land policy which has been followed. Only in a few localities has it been possible to avoid this system and its consequences.

Compulsory overstocking.—The most far-reaching effect of the open-range system is that it compels men to overstock their ranges all the time. A properly adjusted system of land tenure would tend to the automatic removal of the evils which arise from this practice. With laws as they are, possession of any unfenced grazing range containing Government land is to-day held by occupancy only. If a stockman removes some of his stock because he knows there is insufficient feed on the range to supply all the animals till the next growing season, he thereby merely invites some one else to bring stock in and take the feed that has been saved. By this process he loses part of his range and does not avoid the loss of stock that will come later. Yet all stockmen who have large investments and are permanently located in the open-range country recognize these losses as one of the undesirable features of the business and charge up such recurrent losses as a part of the expense of running such a business.

The results of continued overgrazing, in order of occurrence, are (1) reduction of the quantity of the most palatable feed, (2) extermination of the best forage and its replacement by inferior kinds, and (3) continuance of this process till all edible plants are gone and the ground is bare or covered only with unpalatable weeds. Reduction in the number of plants increases erosive effects and hastens the later stages of denudation. The final stage is often bare rock or gravelly arroyo.

On an overgrazed range there is never much, if any, reserve feed, so that whenever a drought occurs the stock must be taken off very soon or in a short time they begin to show signs of insufficient feed. Such forced removals are nearly always undesirable, because prices are likely to fall when there is no alternative but to throw large numbers of animals on the market. With the rainfall as uncertain as it is in the arid grazing region, a system of management which does not provide for a supply of feed sufficient to carry the stock over at least one season of below-normal production is very undesirable. Yet an open-range system of management makes this necessary conservation of range feed practically impossible.

Premature grazing.—On an open range it is the common practice to turn the stock onto patches of young growing feed before the plants have had time to do more than get well started. If one

rancher does not do it, somebody else will; so each must do what he knows to be unwise or suffer a greater loss. This practice prevents the production of seed, hastens the extinction of the best plants, and reduces the total quantity of feed produced on the range that season. Experimental measurements of the amount of dry matter produced by certain cultivated forage plants that were cropped back every week showed that they produced less than one-third as much as similar plants that grew to maturity before being harvested.[15] While this estimate of 30 per cent does not of necessity apply to range forage plants, there is little doubt that the percentage is approximately the same in their case. A fence, therefore, is just as necessary to keep stock off certain areas at times as it is to keep them from leaving an area.

Improper seasonal use of feed.—Frequently on part of a given range there is feed which is good only in the summer and which must be used at that time in order to make the most of it. On another part of the range is feed which may be used both winter and summer, but the stock prefer it at any time to the summer feed. If the stock are sheep, the herder can hold them on the summer feed in the summer time; but if they are cattle they will eat the winter feed in the summer time, allowing the other to be wasted. It is impossible to control cattle on such a range unless the summer feed can be fenced and the cattle held upon it until they get hungry. Once having commenced to eat it they usually do well upon it.

This condition may be reversed as to season. Feed that is available only at a particular time of the year can not be utilized at all unless taken at that time. Stock always eat first what they like best, even though the later consequence of such a practice is starvation.

On certain areas there is a crop of feed available only for a short season. A striking example of this is the abundant and excellent feed on the upper slopes of the high mountains in the middle of the summer. But stock can not stay in these localities during the winter because of the temperature and the lack of feed. Therefore, in order that such feed may be utilized, it is necessary that it be eaten by stock that can come to the region during the summer and go elsewhere during the winter. In other words, it is summer range and must be associated with some winter range in order that it may be used at all.

If winter range of proper grazing capacity is within driving distance for sheep, as it is in certain places in Wyoming and Utah, the conditions necessary for the utilization of the feed are supplied for those who can get control of both kinds of range, provided there is a passageway between with sufficient feed for the stock in transit. If

[15] See Farmers' Bulletin 228, 1915.

the only available range that may be used as winter range is really yearlong range and cattlemen establish themselves thereon and use it that way, or if cattlemen permanently occupy the yearlong range that nearly always lies between the summer and winter range, what becomes of the summer feed which cattle can not go after?

The condition may be reversed. Cattlemen sometimes take their stock up into the mountain forests in the summer and bring them down onto the open, nearby plains in the winter—a common practice in parts of Arizona. Suppose that bands of sheep have grazed over these plains (which are yearlong range) during the summer, and have eaten all the feed. What can the cattlemen do? And again, what becomes of the summer feed in the mountains if the cattle must stay on the plains all the time to maintain possession?

The answer to the question rests in no way upon the kind of business that may be established in the region. Each has its advantages and its limitations. It is just as necessary that we produce mutton and wool as that we should have beef and leather. In many places either business can be maintained and in places where the control of the range has been established long enough for the producers to try out various policies, as in California and Texas, many have found it profitable to run both kinds of stock on the same range [12].

The influence of unprogressive men.—A man who is lazy, or a bad manager, obstinate or quarrelsome, or merely lacks the capital for necessary improvements, is a continual source of irritation to his neighbors on an open range. He either can not or will not do the right thing for the group to which he belongs. He does not develop water where he should for his own stock, consequently they get more water from his neighbors' watering places than their stock get from his. He may be sincere in his belief that salting is not necessary and his neighbors must buy all the salt. He is too impecunious or "conservative" to buy good bulls, hence others are paying for the building up of the grade of his herd and he is doing all he can to keep the breed level down.

There is no way to get along with such a man except to put him where he and his business must suffer the consequences of such shortsightedness; i. e., on an inclosed range of his own. On an open range, such a man very nearly standardizes the grade of business that may be done by everybody, since his neighbors must carry him if they standardize above him. He profits at their expense because of his backwardness or stupidity.

Low rate of increase.—On a stock range the only source of income is the salable animals, the number of which is dependent upon the size of the breeding herd and the percentage of increase obtained.

Animals of breeding age which do not breed are an incumbrance to the business and should be disposed of at once. Moreover, gross receipts depend upon quality as well as numbers of the salable animals. High class results, therefore, are dependent on the degree of control over breeding.

On an open range there is little possibility of obtaining effective control over the breeding of cattle. The ultimate result of this condition is a small percentage of calves per hundred cows of breeding age. When the percentage of increase is small the range is carrying more aninals, both cows and bulls, than are necessary to produce the largest possible number of salable animals. If the percentage of increase is 35 (the estimated average for New Mexico in 1918) the range must carry about 4.5 mature animals for every one that is sold. If the percentage of increase is raised to 70 the ratio is 2.7 to 1, assuming the common type of business of that region, and the ordinary losses. On a controlled range it is not difficult to raise this percentage by the adoption of three or four practices that are easily applied when the pastures are fenced, but which are practically impossible otherwise. The rules of these practices are: (1) Use small breeding pastures; (2) wean the calves at six months, and keep them away from the cows; (3) feed small quantities of concentrates to the breeding animals of both sexes for a short time before and during the breeding season, and (4) keep all steers out of the breeding pastures. By such methods as these it is possible to control the time of dropping of calves and so have a uniform bunch of yearlings to show the buyer when he comes. Much better service can be obtained from valuable bulls in this way, and a larger number of calves from each bull, thus reducing the number of breeding animals necessary and increasing the possible output of salable animals. These practices result not only in a larger number of salable animals but in a higher price for them when sold. (See p. 38.)

Increased expenses.—Another way in which the lack of individual control reduces the net returns of the business is by compelling larger expenses. Open range management of a cattle ranch requires more men and saddle horses at work all the time than are necessary on a fenced range of the same size. An increase in the saddle horses needed makes necessary an increase in the stock horses (breeding mares) on the ranch, with a consequently smaller number of cows. Such an increase in men and saddle horses increases the payroll for labor and the expense for food and feed.

An open range necessitates the semiannual "round-up," which is always expensive, not very effective, and frequently comes at an inconvenient time. The round-up method brings a labor load for a short time that is sometimes very hard to carry. Even under the

best conditions the round-up work is hard on men, horses, and cattle; night guard work is altogether disagreeable, as are other round-up duties. Taken altogether, it is an undesirable practice. Experienced cattlemen who have used both open and fenced ranges all prefer the latter and agree that there is much less work on the fenced range and that the required work is easier. Stock handled in fenced pastures, especially if they are fed occasionally, are usually gentler than those that run on an open range. From the standpoint of the stockman, gentle stock are much more satisfactory to work with and they utilize the feed better than those that are wild and nervous. Open-range conditions tend to produce the latter condition while the fenced range has the opposite effect.

Losses.—The losses so far mentioned are indirect—the result of reduced production of feed, reduced output of salable animals, a lower standard of quality in the animals sold, and an increased expense of production, all of which make for a smaller net income than might reasonably be expected from the business.

The open-range system of management also causes direct losses. The most important of such losses are naturally those which result from starvation of stock during periods of drought.

In addition most ranges produce certain poisonous plants. On an overgrazed range these plants are generally more conspicuous and better grown than others that are good feed, because the stock will not eat them when other feed is obtainable. Hungry stock will eat the poisonous plants, and a certain percentage of them die in consequence.

Some animals "drift" from one watering place to another, causing considerable extra riding to bring them back and the loss of a few head.

A small number of animals are missed each year at the round-up work. Some of such animals should be sold off the range that season, either because they are in good condition for sale or because they are of too poor quality to warrant carrying over another season. Such stock when left on the range are a distinct loss to the business, since they eat feed that should be going to other animals.

Sick animals are hard to find, and many die that might be saved if they could be found in time. This condition is worse on an open range than in fenced pastures.

The custom of New Mexico and Arizona cattlemen is to figure on a 10 per cent loss on the open range. This figure is doubtless an average that includes the big losses from death during drought. Figures obtained from fenced ranges show average losses of from 2 to 3 per cent only. (See p. 38.) Since this percentage applies to the whole number of animals, the possible reduction of loss (7 to 8 per

cent) is alone almost enough to pay the interest on the capital invested in the animals themselves.

Difficulty of controlling disease.—The fence plays a dominating part in the control and eradication of contagious diseases. The quarantine is above all else the most effective measure against the spread of contagious diseases, but it can not readily be used on an open range. Much of the work of the United States Bureau of Animal Industry in the eradication of diseases that must now be handled indirectly could be much more easily managed if the ranges were divided into convenient-sized areas by fences. The spread of certain very dangerous contagious diseases, like foot-and-mouth disease, could be stopped on an open range only with the greatest difficulty, while on fenced areas an effective quarantine could be established as easily as in a farming district.

Unbranded range horses.—In certain regions bands of unbranded range horses are a source of irritation and loss. They are almost valueless to their owners, who fail to brand them in order that they may avoid taxation, yet no one else can put them out of the way without incurring an obligation to pay for them. These animals use and trample out much forage that might be used by meat animals.

Financial drawbacks.—The general precariousness of the business is much greater on the open range, and the degree of complexity of organization possible and the probability of plans being consummated is considerably less. Hence operating capital is more difficult to obtain because of the risk entailed, and the cost of such capital is greater. In the final analysis these difficulties all arise from the compulsory overstocking that can not be avoided on open ranges. The ultimate effect of an open range system of management is to standardize the business at the level of its lowest rather than its highest productivity.

Effects of drought.—At no time do the undesirable consequences of the open range method stand out so glaringly as during a period of drought. Yet such periods, varying in length from one or two to three or four years, occur at more or less regular intervals. They constitute one of the most important limitations of the range stock business, because the supply of feed produced upon the arid grazing lands is practically determined by the amount of water available to the plants during the growing season.

When a drought occurs the stockman must do one of three things: (1) Remove some of the stock from the range, (2) begin or increase feeding operations, or (3) let the stock die. These necessary practices suggest a means of estimating the effects of a drought, from data that give comparisons between results obtained during years of average rainfall and years of drought. The removal of stock

gives rise to increased shipments of stock as well as seasonal displacements of such shipments. Increase in feeding operations results in increased movements of concentrated feeds. Changes in percentages of loss of animals as well as changes in the rate of increase in the flocks and herds are also very suggestive. Reliable data and estimates on these points are available from several sources.

The following data, taken from the report heretofore mentioned, are illustrative, and give as accurate measurements as were to be had of the effects of one such drought:

The annual reports of Secretary T. D. Allen, of the New Mexico Cattle Sanitary Board, show that shipments for 1917 were 161.1 per cent of the average for the previous seven years, while the estimated calf crop for that year was 15 to 20 per cent below the normal average. For 1918 the shipments increased to 177.5 per cent and the rate of increase fell off 5 per cent more.

The records of Secretary Logan, of the Sheep Sanitary Board of New Mexico, tell much the same story, though not quite so conclusively. Shipments of sheep out of New Mexico were mostly restricted to stock sold, and the numbers fell off noticeably. The average shipments out of the State for 1914 and 1915 was over 1,100,000 head, and the shipments in (which are to be considered as purchases of breeding stock in normal years) was slightly less than 10 per cent of this amount. In 1916 (the year the drought began in Texas, but a year of average rainfall in New Mexico) shipments out of the State dropped to 885,000 and shipments in nearly tripled the normal expectation. In 1917 outgoing shipments fell still further (780,000) and incoming (mostly Texas stock) went up to 10 times the normal expectation. The 1918 shipments dropped to 615,000. Normally sheep shipments in this State occur between October 15 and December 15, but during 1918 they occurred throughout the year.

The normal lamb crop for the State is about 75 per cent of the number of ewes of breeding age. For 1917 the best estimate for the State was 45 per cent, while for 1918 it was 35 per cent. Actual figures as to losses were not obtainable, but they were probably large. It was the general belief that the lamb crop in the three southeastern counties of New Mexico would not replace the ewes that died.

Normally it has not been customary to feed concentrates to range stock in Arizona or New Mexico, though a few men feed small quantities to weaklings occasionally. No data as to total quantities of feed used during 1917–18 were obtainable in either of these States, but men who had never fed their stock before in their lives were feeding large quantities of concentrates and hay, although the prices of these feeds were two and one-half times the normal. Many men saved their stock by chopping soap weed or cactus at greatly increased expense for labor and machinery. (See bibliography, sec. 8.)

Individual records were obtained from 40 sheepmen and from 74 cattlemen who were grazing animals in the land-grant area. Various expressions of opinion, estimates and fact were obtained from them, some of which are shown in Table 6. (See also fig. 6.)

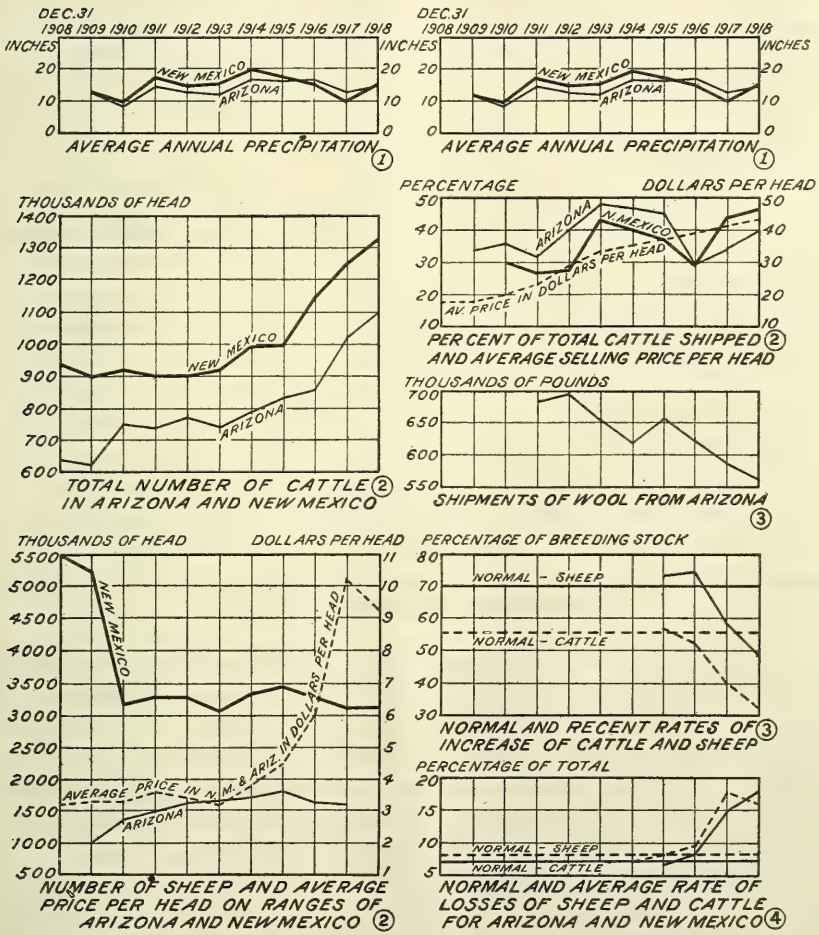

FIG. 6.—Effect of rainfall on the live-stock industry in Arizona and New Mexico.

TABLE 6.—*Data obtained from stockmen using ranges within the limits of the Atlantic and Pacific Railway land grant* [*12.*]

Data.	Cattlemen.		Sheepmen.	
	Average percentage.	Number reporting.	Average percentage.	Number reporting.
Estimates of losses:				
Normal	8	50	9	35
For 1917	16	23	20	10
For 1918	18	37	17	25
Forced reduction of breeding stock:				
In 1917	26	6	60	5
In 1918	16	36	67	7
Rate of increase: [a]				
In 1915	52	19	78	8
In 1916	49	27	76	12
In 1917	45	48	58	26
In 1918	34	58	48	32
Estimated normal	55	44	90	26
	Number who fed.	Number reporting.	Number who fed.	Number reporting.
Supplemental feeding:				
Ordinary practice—				
To feed none	18	42	12	17
To feed a few	6		2	
To feed poor, weak stock	18		[b] 3	
In 1917—				
Fed none	.....	14	.....	.....
Fed a few	5		.....	
Fed a large number	9		.....	
In 1918—				
Fed none	5	30	.....	11
Fed a few	8		1	
Fed a large number	16		6	
Removed stock	1		4	

[a] Based on number of breeding animals. [b] Feed bucks.

SOME BENEFITS ARISING FROM FENCING THE RANGE AND CONTROLLING THE METHODS OF USE.

In contrast to the disadvantages of an open range are the positive advantages that may result from individual control. Experience on privately owned ranches of large size, as well as experimental results obtained where all the factors were known and measured, show that in many ways the business may be better organized, rendered more productive, and relieved of many of its uncertainties by simply giving the present user a legal right to control the land he now uses.

A change in our laws which makes it possible to grant to an individual, or a small group of individuals acting together, the privilege of grazing stock upon a specified portion of a National Forest, for a limited time and under definite regulations, has resulted in marked advantage to the users, even though the permit has only occasionally carried with it the privilege of fencing the land used. The establishment of a legal method whereby the arid grazing lands might be fenced in units of convenient size would revolutionize the business by removing the obstruction to its orderly development. Of course mere control of itself does not necessarily bring about the improved

organization and better managerial practices. The experience of the stockmen of western Texas during the recent drought demonstrates that it is easily possible to overstock fenced ranges. But fenced ranges render possible many improvements in organization and practice that are impossible on an open range, thus eliminating or at least minimizing the disadvantages previously discussed. (See bibliography, sec. 10.)

Increase in quantity and quality of feed.—Probably the first and most important effect of control would be a marked increase in the quantity of available forage. This has been the almost universal experience upon ranges that have been inclosed. (See bibliography, sec. 7.)

Besides the increase in the total amount of feed produced on the range, the fence also makes possible the maintenance or improvement of the quality of the range feed. All that is necessary to bring about this result is to allow the plants to go to seed at frequent intervals. Deferred grazing, as this practice is called, and rotation of pastures result in more feed and better feed [82], an assured supply of feed on the ground all the time, a reduced run-off, and the consequent better utilization of the water that falls.

It is upon such fundamentals as these that the prophesy of marked increase in production on controlled ranges rests, especially when taken together with an increase in the percentage of young produced. Such prophesies are not mere statements of theoretical possibilities; they have been convincingly fulfilled wherever the system has been carried out.

Introduction of valuable plants.—The improvement of the grazing capacity which may be expected to occur automatically upon a well managed controlled range is but the beginning of the total ultimate increase in feed which may be expected. There are numerous ways in which this increase may be brought about. Living now upon the ranges may be found certain kinds of plants that are better adapted to the environment than others, and which are at the same time better adapted to grazing uses. Individual plants of a given species possess variations that are economically valuable. Such plants, by proper treatment, may be made the dominant forage on a range, thereby considerably improving its grazing capacity. Shrubby plants of known value are very desirable on parts of the winter ranges, especially when such ranges are occasionally covered by heavy snow. There are forage plants which have not yet been tried out that will increase the forage output of much of such land. Little has been done toward such improvement of the range feed, and there is very little incentive for efforts of this kind, because as long as the stockmen have no control over the land which they use none of them can afford to make experiments.

Relatively little [16] is known of certain steps in the life histories of some of the best of our native forage plants, and almost nothing of what may be necessary in order to get more abundant reproduction of such plants. Some such experimental attempts have been made—mostly by planting seeds—but nearly all such efforts have given negative results. Some attempts at saving the run-off have proved partially successful, but they are rather expensive [74]. Further studies in these directions are amply warranted, especially with respect to the treatment to which seeds of certain valuable forage plants should be subjected in order to secure sure and rapid germination and growth.

Some results of experimentation.—Carefully conducted experiments on the Jornada Range Reserve in south central New Mexico, by the Forest Service, in cooperation with an experienced stockman, have yielded some very accurate figures that are practically conclusive proof of the advantages of an improved type of range management possible only on fenced land. This reserve contains approximately 200,000 acres of mountain and plain grass-land, mostly of forage type No. 2, the semi-desert grass land (see p. 14), and carries from 3,000 to 5,000 head of stock, depending upon the annual climatic variations.

The annual reports of the Forester contain the following data:

The losses from all causes in 1915 were 1.9 per cent; in 1916 1.5 per cent; in 1917, 1.8 per cent; in 1918, 3.5 per cent, and in 1919, 1.5 per cent. In a herd of 500 selected cows that were carefully managed, the loss in any year has not exceeded 1 per cent. Estimates of losses of herds on unfenced ranges in the same region show about 15 per cent for 1917, and range from 15 to 50 per cent with an average of 25 per cent for 1918. Cattlemen in New Mexico ordinarily estimate their average losses at 10 per cent.

The average calf crop on this reserve for 1916 was 72 per cent, with 81 per cent for the selected herd and 69.2 per cent for the main herd. For 1917 these figures were 64 per cent, 68 per cent, and 61 per cent; while in 1918 they were 62.2 per cent, 80 per cent, and 55.4 per cent, and in 1919 43.0 per cent, 52.0 per cent, and 41.8 per cent, respectively. The estimated calf crop for the State is as follows: Normal, about 50 per cent; 1917, 33 per cent; 1918, 30 per cent, and 1919, 25 per cent.

The results obtained on this controlled range are thus shown to be about 50 per cent better than the average for the State, though the

[16] The writer would be the last to belittle in any way the careful work that has been done in this field, much of which is not yet published. He knows too well the difficulties of the subject. But the fact remains that very much more information is necessary. It is a notable fact that on much of the range country to-day, some of the more important forage plants are accidentally introduced European weeds. Such a condition suggests the great possibilities of properly selected introductions. Information as to the best methods of securing germination of the seeds of the more valuable native range plants is still scanty, yet such information would be very valuable in securing rapid recovery on ranges that have been practically denuded.

range is naturally about as poor as any of the arid grazing land in the State [79]. The losses are almost negligible, compared with those sustained by herds on the immediately surrounding open ranges, and show only nominal increase during the years of drought. Of course these results are to be attributed to good management, but good management is largely dependent on the power to control the use of the range.

Some suggestive results of experience.—Among the men interviewed in Arizona and New Mexico, previously referred to, were two cattlemen who have been in the business in that region for many years.[17] Their experience is highly suggestive; it is the same as that of many other men operating fenced ranges. Both are very careful in their statements. Each had succeeded in getting control of what is ordinarily considered a not very large ranch for that region. Each of these men stated that instead of deteriorating, their ranges had actually improved during the drought. One of them said he had made more money from the fenced range than he had previously made from twice the area before it was fenced. The next neighbor of the other had been compelled to take all his stock off his unfenced range to keep them from dying, yet the increase in feed on the fenced range during 1917 had saved about $2,000 on the feed bill, and rendered feeding unnecessary in 1918. Such results as these are only possible on fenced ranges.

Advantages to sheepmen.—It may be objected that most, if not all, of the arguments so far presented apply only to the production of range cattle; that sheep get along on open ranges much better than on inclosed ones; that in order to utilize to the fullest the summer feed of the high mountains, sheep must be used in traveling bands, and that areas of winter feed with connecting driveways must be reserved for such animals; that such a method of management is the most effective and least expensive; that if the fencing up of separate holdings be allowed many sheepmen will be forced out of business, and that we as a nation will be compelled to depend upon other nations for our wool and mutton.

No one knows better the effects of the "tramp" band of sheep than the sheepman, because he has suffered from these effects himself very frequently. And no one has profited quite so satisfactorily by the grazing policy applied in the National Forests as the so-called "small sheepman."

Many sheepmen are strongly in favor of a subdivision of the range because they know by their own experience that they could carry on their business much better on a controlled range. Many of them are acquiring land and other equities as rapidly as possible. Some of

[17] Mr. Frank F. Moore, member of State Cattle Sanitary Board of Arizona, Mr. J. H. McCamant, sheriff of McKinley Co., New Mexico, and vice president of the New Mexico Cattle and Horse Growers' Association.

them would at first object to fencing because they think they do not need fences, and the sheep business can be carried on without them. It has been shown, however, by carefully conducted experiments that under high mountain range conditions part of a band of sheep running in pasture without a herder, but protected by wolf-proof fences, did better than the remainder of the same band on adjacent open range under the care of a herder. The animals inside the fence were heavier, produced more and cleaner wool, grazed a smaller area and trampled it less than those outside under a herder's care, and the losses were practically identical [76].

The plan of handling sheep in large pastures inclosed with coyote-proof fences has been in operation with success in certain counties of southwestern Texas for a number of years, and much of the land is fenced in this way, notwithstanding a first cost for fencing that seemed almost prohibitive. Yet the men who have tried it are pleased with the results obtained. (Of course this generalization can only apply to yearlong ranges or their equivalents.)

A number of the sheepmen in Arizona who are surrounded by cattlemen are as anxious for the cattle to be fenced in as the cattlemen are. One experienced sheepman at Holbrook, Ariz., succeeded in running a band of sheep all year long with a loss of only 27 animals from a band of 2,200 on an area where he was not interfered with by other stock and had virtual control. Yet the range he used is not considered a good sheep range at all, and he had been in the habit of leaving it part of each year. These experimental and actual business experiences tend strongly to prove that what has been said of the value of separate, fenced areas of sufficient size is as true for sheep as it is for cattle. Such a policy would doubtless necessitate certain changes in the ordinary practices, but the net result would be safer and more productive business, with better returns for less work.

Sheepmen in certain regions are now debating the question whether they can ship their stock from one range to another more economically than they can drive them. Some are actually shipping them. Range sheep are driven from summer range in the mountains of Utah to winter range on the deserts and pass through the irrigated farming lands that lie between with no other driveway than the public roads. This has been done for years. Driveways are unquestionably necessary in certain regions, but they should not be used as pasture grounds by the first bands as they pass, thus destroying their usefulness for later bands and providing either necessity or excuse to these later bands for trespassing upon the permanent ranges through which they pass. Adjustments of all these difficulties, which under the present system cause great bitterness, can be made at once by fencing, and should have been made long ago for the best interests of all concerned.

Fences.—The best control is that afforded by properly arranged fences, though this method of obtaining control involves a heavy expense. Yet many, if not most, of the stockmen are ready to begin the work of building long strings of fences that will outline the major subdivisions of the range country just as soon as they can obtain legal authority to do so.

With nothing more than the legal recognition of the right of a particular man to use a given area for a limited time, the existing laws will stop trespassing at once, because the precedents are already established in the region by experience in the national forests. And with legal tenure assured, the building of fences can go on as rapidly or as slowly as individuals may choose.

Fencing need not prevent entrymen from homesteading agricultural land, nor prevent prospecting for minerals. It merely protects the equity of the user of the range and makes it necessary for the would-be entryman to take expert judgment as to the proper classification of the land. As already pointed out, it has been demonstrated many times that fencing in proper sized areas is not only practicable economically but is highly remunerative. The increased returns from a fenced area in a very short time pay for the fence. Even on a range of relatively low grazing capacity, the protection which a fence affords makes it a profitable investment.

Advantages to the general public.—Benefits which would accrue to the State as the result of controlled ranges are, (1) an increase in the taxes derived from the stock business because of the value of permanent improvements like fences, corrals, watering places, and other "developments" which will be made as soon as men can be sure they will profit by what they may do; (2) increased taxes because of more accurate counts of live stock that are possible on inclosed areas; (3) increased rentals from State lands which men will have to pay whenever they inclose such State lands in their pastures.

Objection has been made to Federal regulation of the grazing lands because it was assumed that the State would not get the right to tax such lands. This has been advanced as an argument in favor of a law that would either put the land under the control of the State or assign it to private ownership so that the State might tax the owners. Any sort of managerial supervision will result in the charging of some kind of fee for the use of the land. The policy of sharing receipts of a similar character between the Federal and State Governments is already established in the administration of the national forests. Hence an extension of such a practice is to be expected with relation to grazing lands if they were placed under Federal management.

In a more general, though not less sure way, the people at large benefit by such range control. The resulting increase in production

of meat, wool, and hides, which is unquestionably advantageous to the producer, also benefits the consumers of such products. An increase in the production of the region means that it will carry a larger population, which in turn makes for an increase in the complexity of type of civilization. Hence, from every standpoint, i. e. the welfare of the ranges themselves, the advantage of the users of the range, the benefits to the State and Nation, there is advantage to be gained by any sort of legislation that will make possible the fencing up of the arid grazing lands.

Adjustments.—Nor is there any one with any real equity in the region under consideration who must of necessity suffer serious loss. Naturally, many of the claims now made by stockmen will be shown, on careful examination, to be much exaggerated. All such claims would have to be passed upon and settled whenever an adjustment is made. The "tramp" sheepman, who has no equity in the region, will disappear. Adjustments between summer and winter range can be made, and when made will put the business of using both on a much less precarious footing than that upon which it now rests.

These necessary adjustments in the use of the arid grazing lands could be made most logically and quickly by a supervising authority that is able to study the ranges of an area as large as a State, or possibly parts of two States, and adjust the subdivision so as to utilize the whole to the best advantage. But this method is not the only one. Individual control of separate areas will at once settle the problem in some fashion, and though it may not at first be the theoretically best adjustment, this best adjustment will ultimately be reached simply because it is the most productive adjustment and therefore most remunerative. The application of either method of adjustment rests upon legalized control of the range lands and is not possible on an open range.

THE NECESSARY LEGISLATION.

In a consideration of the problem of the changes which it may be desirable to make in our land legislation it is wise to state specifically and somewhat formally the various assumptions and ideals that have been taken for granted as basic to the discussion. With these assumptions in mind the requirements of the situation should also be definitely presented. And, finally, the various kinds of legislation which have been proposed should be carefully considered in detail.

BASIC ASSUMPTIONS.

It is assumed that the discussion applies only to those regions where, on account of prevailing aridity, cultivated crops can not be produced with sufficient regularity to render crop farming a safe business. While there are many places in which some incidental

crop production may be carried on as subsidiary to stock raising, there are also large areas in which not even this is possible.

It is also assumed that the basic principle of the existing homestead laws should be maintained; i. e., that provision should be made for creating opportunities for men of small means to acquire homes substantially free of cost, except incidental fees, by fulfilling certain requirements as to residence, improvement, and use of the lands. To render such a policy practicable, however, the area of land granted must be large enough to constitute an economic holding; i. e., an area sufficient to support a family in reasonable comfort. It is essential to recognize two facts. First, as already stated, the production of crops on such lands can be only incidental to the carrying on of the live-stock industry and can not be the principal use. To attempt to apply a homestead policy to this region on the assumption that crop production will be a basic enterprise simply has the effect of encouraging many men to undertake to improve their condition with certain prospect of failure. At the same time such men displace actual users of the land. Moreover, the present users are by no means all large ranchmen, many of them being small holders now occupying tracts little more than sufficient in size to maintain a family. In other words, a homestead policy that follows the lines established for the crop-producing homesteads of the humid regions or even of the dry farming regions, fails to establish small holders on the lands and at the same time actually dispossesses numerous other small holders who are already adjusted to the conditions of the region. The second fact to be recognized is that even a small holding policy in the arid grazing land must contemplate holdings of several sections of land, the amount varying with its productivity.

Finally, it is assumed that however desirable the ultimate working out of a small holdings policy may be, it is entirely uneconomical and unreasonable to attempt its application in such a manner as to disrupt the established industry of the region. The policy should be gradually developed, so that the total economic cost to the Nation of the process of readjustment will be as small as possible. It is also recognized that other size adjustments may prove more suitable in the long run than such economic holdings, and the way should be left open for such possible adjustments. In no case should subdivision into areas of less size than the economic holding be permitted in an attempt to improve upon the existing adjustment. This principle is illustrated in the Texas leasing system, which recognizes a limit to which the leasehold of a large holder may be reduced by incoming lessees or purchasers. One of the merits of the permit system worked out on the National Forests is that the homesteader is admitted without allowing him seriously to disturb the existing

adjustment among the present users. In fact, what has here been called an "economic holding" does not necessarily represent a holding of the minimum economical size from the point of view of efficiency in the use of the resources of the region. The way should always be left open even for the homesteader to enlarge the scope of his operations, provided such enlargement is in the interest of efficiency.

Fundamental to the making of any law is the realization that in operation the proposed law must start with the present status of the business and take that next step in development which leads toward the ultimately desirable. The present adjustment works, in a way; the proposed adjustment must work better or there is no advantage in changing. It is not possible to clean the slate and start the problem over again, but it is possible to make changes in rules of procedure which will ultimately change the whole business for the better, with less injustice to any one than results from the present procedure.

REQUIREMENTS THAT MUST BE MET.

Legislation for the improvement of conditions must recognize the equities of the present users, which should be considered not only from the standpoint of justice to the men who possess them but from the more important one of the best utilization of the land. Several of the equities have been mentioned, but no summarized list of them has been made. They are: Resident ownership of land; nonresident ownership of land with or without stock-water; stock-water of any kind, such as wells, springs or streams, reservoirs, pipe-lines and other improvements; squatter's right to unsurveyed land; homestead entryman's right to land entered but not yet patented; lessee's right to leased land; mining claims held on assessment work; priority rights of citizens as against aliens, and in some measure mere priority of use.

The difficulties to be overcome in the adjustment of claims for all such equities have been met in one way or another in the administration of the National Forests, and the experience of the administrating officials should prove suggestive and helpful.

The right of governmental withdrawal of land from entry or use, in accordance with law, is not to be questioned.

In the present state of public opinion it is probably wise to continue the homestead policy as a method of disposing of lands suitable for crop farming. If a reasonable minimum limit of productivity were maintained, the existing homestead laws need not seriously interfere with the proper use of the arid grazing lands. It is doubtful if this has been done, notwithstanding laudable efforts that have been made in that direction. These laws could be given precedence over any others designed to control the arid grazing lands.

The right of the Government to charge a reasonable fee for the use of Government land must also be maintained.

It is of the utmost importance that controlling officials who might be charged with supervision of the Government grazing lands should have the power to say how many animals may be put upon a given area of land, for upon this power rests the whole plan of building up the ranges.

It is recognized that today many of the ranges which are individually operated are much larger than the ultimately desirable size. It is not desirable that they should be broken up into smaller holdings at once and parcelled out among a number of men who have neither the capital nor the knowledge necessary for their use. Such a procedure would be disastrous in many ways. But the fact that a better use adjustment of these large areas is desirable and possible must be admitted, and a procedure should be inaugurated that will lead gradually and without injustice to any one toward the final proper adjustment in size.

The only existing "right" which should be curtailed is that of the unregulated use of the public domain.

METHODS PROPOSED.

The following general policies for meeting the problem of range control have been proposed at one time or another, and most of them are now or have been in use in this or other countries [12]:

1. Sale of lands, with or without restrictions as to the area that may be purchased or the person to whom the privilege is open.
2. Gradual enlargement of the size of the area that may be homesteaded.
3. Introduction of a federal leasing system.
4. Consolidation of private and federal holdings by exchanges.
5. Transfer of the federal lands that lie within their several boundaries, to the separate States, for administration.
6. Establishment of a permit system, similar to that in use in the National Forests, for the control of the federal grazing lands.

Sale of the lands.—Little need be said of the policy of selling the lands, except possibly to clear up a few misconceptions. As all who have read the history of our land policy know, this was the method of disposal of public lands in use until the original homestead law was passed, and it is still possible to "commute" a 160-acre homestead by purchase. The present general popular prejudice against this method arose as the result of land speculation abuses during the first half of the last century, and the change of policy was due to a warranted change in public opinion as to who should profit by the distribution of the public lands.

Though it is not now possible to buy Government land in large acreages, there are still on the statute books laws which make it possible to purchase certain kinds of land in specified small areas.

Hence, in two ways the policy is still recognized, though with restricted application.

Really very little harm would be done if a policy of selling the remaining public lands of the United States (not including Alaska) were inaugurated, with proper restrictions, if we assume that individual ownership of lands is the best adjustment of the whole question. The reason for this lies in the character of the lands still to be disposed of. If the equities of the present users of these lands could receive proper consideration, and priority of right to purchase be granted them on the basis of their equities, the great bulk of these lands would soon pass into the hands of the present users, though it is practically certain that many applicants would get less land than they now claim as their own ranges. It must be kept in mind that these men are already carrying on the business for which the land is best fitted; that they have large investments in improvements in the region; that they want to stay in the business; and that most of them know how and desire to increase the productivity of this land.

This adjustment would have the disadvantage of fixing the status of the land approximately in its present state of subdivision, which is recognizedly not the best possible adjustment. It would also give special advantage to the man who has plenty of money, since he is the man who can buy, and he could use that power to the disadvantage of others who would need the land for use.

If legal control of the range lands by those who use it were all that is wanted, this method would give it, and to that extent it would be an improvement over present conditions. But a much better type of control is possible.

It is not likely that we will ever revert to the policy of unlimited sale, since the disadvantages mentioned have been recognized, and public opinion is strongly opposed to the practice.

Gradual enlargement of the homestead area.—Underlying the original homestead law and all modifications of it since passed, is the assumption that the entryman is to receive, as a gift from the Nation, an area of land which, if properly worked, will furnish him and his family a reasonable living. In the humid region 160 acres of farming land was rightly judged to be amply sufficient. The law was made when everybody considered the areas here referred to as semiarid and arid grazing land, to be a part of the "Great American Desert," and few expected that it would ever be used for any kind of agricultural purpose. At that very time, however, there was growing up the industry which led the way to the occupation and use of these lands—the range grazing of stock.

With a continuing demand for farming land, and after most of the available land of the humid region had been taken, men began what we now call "dry farming" on the best of the semiarid lands. A

common practice in dry-farming areas is to allow the land to lie fallow every other year, hence, it was argued, a farmer must have twice as much land in order that he might raise the usual amount each year. Therefore, a law was enacted by which he might obtain 320 acres, or what really amounted to two farms. The act which thus extends the original idea is known as the Enlarged Homestead Act. And though it was passed after much of the true dry-farming land had been taken under the older laws, it worked fairly well on the lands for which it was designed. Both of these homestead laws assume that the entryman will, by his efforts, be able to cause his land to produce more food and feed than it normally produced without his labor.

Some men made failures on land taken under the 160-acre law because the land was dry-farming land, and they didn't have enough of it. Those who obtained a proper-sized area and learned dry-farming practices demonstrated the possibility of utilizing the land in this manner. The reason for the failure of some was not properly appreciated, hence little surprise was felt when men failed to farm a large part of the land that was taken up under the 320-acre act. The losses of these homesteaders were accepted as proof of their ignorance of dry-farming practice, while in reality they failed because they did not have enough land to carry on a profitable type of agriculture. Likewise, the disruption of the grazing business which occupied this land before the homesteaders came, and the fact that after a period of adjustment a relatively large part of the land went back to its original use as grazing land, have also not been properly recognized.

Acting on the assumption that the practice of gradually enlarging the homestead area had been demonstrated to be wise and might be continued, step by step, until all the available public lands had been transferred to private ownership, the Grazing Homestead Act was passed in December, 1916. By it a man may take as a homestead 640 acres of lands that have been designated by the proper authorities as "chiefly valuable for grazing and raising forage crops, do not contain merchantable timber, are not susceptible of irrigation from any known source of water supply, and are of such a character that 640 acres are reasonably required for the support of a family."

It will be noted that the law anticipates that forage crops will be raised by the entryman as a principal means of subsistence, and that an area of 640 acres is assumed to be sufficient.

When this law was passed practically all of the remaining unpatented public land was grazing land of very low productivity. In classifying the land, such of it as had less than 80 acres of possible plow land on the section and was believed to produce enough native forage to carry 25 head of cattle was designated as open for entry under this law.

An extension of the application of the law was soon made which allowed entrymen who had taken up land under the 320-acre act and had been unable to make a living on that area to enlarge their holdings to 640 acres. It is probably correct to say that this extension of the law has been beneficial to most of those concerned, because 320 acres is not enough in much of the area that can be dry-farmed.

Millions of acres have been taken that, though they will produce certain crops (mostly forage) during favorable years, will not produce these crops during the years of drought which occur at more or less regular intervals. The area of land plowed for crops on a grazing homestead reduces the grazing area of the farm by just so much, and therefore reduces the number of animals that may be carried on the grazing land alone. Yet these animals must furnish the income for the years of crop failure.

The grazing of stock on the native forage produced on the land is an enterprise upon which the entryman must depend either part or all of the time, and the possible output of salable animals becomes very important. If the maximum number of animals that 640 acres will carry is 25 and the land will not raise any crops, what can a homesteader hope to get from his grazing homestead? With a 90 per cent increase (which is 10 per cent better than is to be expected) and a 2 per cent loss (which is very light) and assuming that all his cows are of breeding age he would have 21 salable animals at the end of the year. Twenty-one animals sold at $40 per head (which is a high price) would give him $840 as gross receipts from which he must pay the expenses of the business and his living expenses. This estimate is made for that type of business which brings the greatest returns, and would be realized only under the most favorable circumstances; such circumstances could not be expected to occur regularly.

This lower limit of productivity of the land, which is that originally established for purposes of land classification, is believed, by many who have considered the subject, to have allowed would-be settlers to enter land which was too poor to support a family in reasonable comfort on 640 acres.

The statement is often made—and believed by many—that the introduction of crop farming into a region increases the rainfall of the region, or, as it is ordinarily worded "the rain follows the plow." The records of the U. S. Weather Bureau demonstrate beyond question that this is not true. Plowing the land frequently does diminish the run-off, thereby improving the utilization of the water that falls, but when the total amount of water that falls is too small for the production of the crop, plowed land will produce nothing at all or but a scanty growth of weeds. Normally such land, if it has not been plowed, will produce a growth of native grasses or shrubs even during the dry seasons to which it is frequently subjected, but when

the land is plowed these plants are destroyed and it takes many years for them to reoccupy the soil after cultivation has ceased. It therefore is clear that when an entryman attempts to cultivate land whose productivity is so problematical, he is taking a very large risk of losing everything he puts into the venture.

Probably the surest way of determining whether or not some of this and will produce crops profitably is to try it. Large areas of it certainly will not. Other areas will, part or all of the time. These areas that will and will not produce crops are often in close juxtaposition. Such lands, because of their relation to each other, are best used together.

To the entryman who is not acquainted with the climatic conditions much of the land, judged from the character of the soil, looks like good farm land, and it is very difficult to make him believe that it is not. He may be and usually is acting in perfectly good faith when he asks to be allowed to homestead it and says he is ready to risk his accumulated capital, his labor, and his family on the venture. He is often poorly informed and suffers in consequence.

A still worse situation sometimes arises. The homesteader may be able to grow crops on his place for a few years in succession and seemingly succeed. This is taken to mean the absolute proof that his judgment was correct. Then comes a drought lasting one, two, or three seasons, and the farmer learns the truth. His former temporary success, however, has been the undoing of the whole region. Many homesteaders have come in; the range has been broken up; the stockman has had to move out because he had no feed; much of the native vegetation, the only kind that will stand the drought, has been destroyed by the farming operations. The land is neither grazing land nor crop land. The stockman is gone and the crop farmer has to go in turn.

This condition has arisen in place after place simply because men have improperly estimated the agricultural possibilities of the land. In the present state of our knowledge there is but one criterion by which to judge. Arid and semiarid lands should be recognized as grazing lands and treated as such until it is demonstrated that sufficient crops either of forage or of grain can be grown upon selected areas *during the dry years* to guarantee, in conjunction with the associated grazing land, a living to the occupant.

All of this land which the public assumes to be unoccupied is already *in use* by citizens who have greater or less equities in the region by virtue of priority of occupation, continuous use, and monetary and other expenditures in its improvement for production. These persons are and have been for a long time permanent residents of the region, interested in its development and carrying on a business which has been making the land productive of commodities that

are just as necessary as those that the incoming homesteader hopes to produce.

As the grazing homesteader will always select the best of the grazing land, his activities are likely temporarily to drive out the range grazing industry, and the present user will lose most if not all of his equity, although the introduction of a more productive type of agriculture frequently is decidedly doubtful if not impossible. When the present occupant tells the new man that it will be impossible to grow crops on the land, the latter immediately judges the advice to be insincere. It has happened over and over again that the stockman is correct and the homesteader loses all he puts into the venture; but his advent has at least temporarily driven out the stockman.

However, the fact that some of the land will produce crops part or all of the time must not be overlooked. Recognizing that it is very desirable to make the land produce as much as possible, it would seem wise to approach the problem of how best to use this land from the standpoint of the range stockman, who is already using it and frequently best knows its possibilities for crop and live-stock production, instead of from that of the prospective homesteader who doesn't know the country.

The well-informed range stockman to-day fears the homesteader merely because he doesn't want his range broken up, and recognizes that with the laws in their present form he has no recourse for the losses, amounting to confiscation, which he may be forced to endure. If there is any land on his range where crops can be grown he is ready to buy the feed produced on it if there is any way of restricting the crop farmer to that land which will grow crops. But the stockman's hold upon the land that he uses is now of so uncertain a character that he dare not demonstrate that certain small patches of his range will produce crops occasionally. If he had a legal right to the use of all of the land he now does use, it would be to his advantage to search out these small spots, where additional feed can be produced, and cultivate them. Under the circumstances that now exist, he will do all he can to dissuade any one from trying such a thing on "his" range.

Yet if he knew he would not harm his main business, but rather help it by so doing, he would be willing to invest money, labor, and seed in an attempt to produce a little extra feed on such land. In this way even the temporary crop land would be brought into cultivation without disturbing the stock business, and the ultimate result would be the same so far as total production is concerned. This method would have the other advantage of avoiding the losses that the great majority of the homesteaders now suffer, to say nothing of those of the stockman. While the crops on such land might fail several times in any decade, the crops produced during good years would more than reimburse the stockmen for any losses; the loss of

a crop would be merely an incident in his business and would mean only a smaller total income than usual. A partial failure of a grain crop is not proportionally so great a loss to the stockman, because if he gets as much forage off the plowed land as it would have produced in native grass he has lost nothing but the work and the cost of the seed; but the failure of crops for several years spells absolute disaster to the crop farmer. That any and all known cultivated crops will fail on such areas a certain number of seasons in a period of years has been demonstrated time and time again and the generalization can be accepted as proved.

It has been urged that if the existing homestead laws be allowed to operate for a sufficiently long time, the lands will pass into private ownership, and the necessary adjustments in the sizes of holdings can then be made by the owners. Such a contention is true only when *all* the lands are privately owned. This condition is reached only after long delay or not at all, because much of the land is so poor that no one wants it. Even small scattered areas of such public land to a very large degree prevent the fencing of the remainder.

The annual reports of the Commissioner of the General Land Office show that while some land is being homesteaded a part of it is being left in all of the States of the arid grazing region, ranging in amount from a small part in the State of Washington to more than three-fourths in Nevada. The rate at which the lands have been taken in these Western States differs with the State and fluctuates with the years, but shows a general tendency to decrease in all of them. The fluctuations do not seem to be in any way correlated with the changes in land legislation. The one important fact that is deducible from the data is that much of the land is being left as public domain. Table 7 shows the total acreage entered each year since 1910 in each of the 11 Western States. The area still open for entry in 1920 and the total area of each State are also given for comparison.

TABLE 7.—*Total entries*[1] *of public lands (all classes) for the 11 Western States 1910-1920, inclusive.*

[Millions of acres.]

Year.	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	Area still available 1920.	Size of State.
Arizona	0.5	0.5	0.7	0.8	0.8	0.3	1.9	1.4	1.2	0.5	1.8	18.3	72.9
California	1.2	1.1	.9	.9	.9	1.0	.6	.7	.3	.5	.9	19.6	101.3
Colorado	3.8	2.1	1.2	1.3	1.3	2.5	2.9	1.9	1.1	1.6	1.8	8.9	66.5
Idaho	1.7	1.1	.8	1.0	.9	1.1	1.1	.8	.6	.7	.9	8.8	56.7
Montana	6.5	4.3	3.6	3.7	5.3	4.1	3.7	3.8	2.4	1.6	2.2	6.0	94.1
Nevada	.2	.3	.3	.2	.2	.3	.2	.1	.1	.3	.2	54.2	70.8
New Mexico	1.9	1.4	1.1	2.3	1.9	3.3	2.8	1.9	1.0	2.2	1.5	18.4	78.5
Oregon	1.0	.7	.7	.6	.8	.7	.6	.4	.3	.4	1.0	14.0	61.9
Utah	.5	.5	.5	.2	.2	.4	.3	.3	.2	.2	.4	30.0	54.4
Washington	.5	.4	.3	.3	.3	.3	.2	.3	.1	.1	.2	1.1	44.2
Wyoming	1.4	1.2	.5	.7	.9	.8	1.4	1.5	1.2	2.3	3.9	19.7	62.7

[1] Entry is the term used for all sorts of applications for public land that have been allowed by the officials of the land office. The area ultimately patented is usually considerably less than the area originally entered.

The demand for free farming land is so great that if this land could have been cultivated successfully it would have been taken long ago. The entryman has been kept out by adverse physical conditions, mostly climatic, that have determined the possible use of the land.

If it be assumed that the land of a given region, formerly occupied by stockmen, has all been taken by settlers who believe that they can farm it, and that the land is really arid grazing land, what actually happens in such a region? It is a foregone conclusion that arid grazing land will ultimately be used as grazing land, no matter what mistakes men may make in their attempts to classify it. The cycle from stock raising to stock raising again generally pursues somewhat the following course:

The settlers take up the land until the occupying stockman, being deprived of his range feed, is forced to sell his stock and other property, usually at considerable loss. The settlers use up their money making necessary improvements, buying equipment, and paying living expenses, in anticipation of a crop. If the crops fail, they are forced to borrow money and give the money lender a mortgage on the land and equipment. The crops fail a second time and the settlers must give up their land and equipment to pay their indebtedness. They then usually leave, heaping curses on a region that they have themselves helped to put out of use. They have lost all their original investment, all the borrowed money, two or more seasons' work, and they and their families have endured many hardships, merely because they were mistaken in the land classification. The land is left in the hands of the money lender and it must lie idle until he can sell it or lease it. If a sufficient area, lying in a compact body and properly watered, can be bought at a price which the business will warrant, some stockman may be willing to buy the land and start stock raising again. Several more steps may be introduced into the cycle, usually with a loss at each transfer, and a prolongation of the period of disuse.

Nothing has been gained by this cycle of changes except the legal control of an area of sufficient size to carry a productive stock business, and this end is not attained unless all the land in the original area is patented by the settlers and all of the land so taken may be purchased at a reasonable price. It should be possible to reach such a desired end in a much more straightforward way, without the losses that result from this indirect method.

A cycle of changes more or less similar to that described has been going on for years in the semiarid region as the result of the policy of gradually increasing the maximum size of the homestead area that may be taken by an entryman.

It thus becomes clear that a policy of gradually increasing the size of the homestead not only tends to destroy a legitimate business

now more or less well adjusted to the conditions, but it also frequently induces misinformed men to attempt what can not be done, with consequent loss and suffering to themselves, their families, and the public that has to pay for their mistakes.

Besides this, the general plan makes it possible for a certain type of man to play upon the credulity of the sincere farmer and for others to blackmail the stockman who has large investments in his range.

From every standpoint the system is thus seen to be a poor one. It not only does not introduce a higher type of industry into the region but it displaces the industry that is already there and leaves the land in worse shape than it was originally.

Government leasing system.—A government system of leasing is today in operation on grazing lands in Australia, New Zealand, and Texas and on certain lands of other States. Various justifiable criticisms of it have been made, but in operation it produces much better results than the open-range system now compulsory on our arid grazing lands. It authorizes individual control of the land for a considerable period, and by so doing encourages the stockmen to use their best skill in its management. This is the most important result of any system of control and the main thing sought. To that extent the leasing system is to be commended.

There are two serious objections to the method, though they are not insurmountable. Existing custom with respect to land leases assumes that the lease transfers the land to the lessee for his individual use for a given period of time, and leaves the character of the use to his judgment. The price paid for the use of the land is ordinarily expressed as so much per acre. Consequently there follows a tendency to overstock, particularly toward the end of the term of the lease, and a continual squabble over the price. To avoid these difficulties, it would be necessary to include in the lease a statement of the number of animals that might be put upon the land, retaining the privilege of counting them at any time. And this number of animals and the price per acre or section should be based upon the grazing capacity of the land, making the charge constant for an animal unit. However, when these conditions are written into the lease, two of the main features of the permit system have been introduced.

The second serious difficulty lies in the fact that the kind of law that will suit the conditions in one region will not do at all in another place; and so far no one has been able to devise a lease law that would cover all the necessary provisos and exceptions and properly localize the application of such limitations. Because there has been no way of getting the men most affected by such a law to agree on a form of law that all would be willing to support, the opponents of any and every sort of change in the *status quo* are able to argue that these

would-be improvers can not agree and are squabbling among themselves for personal advantage instead of seeking a general improvement in range management such as they profess to be doing.

While objections to a lease law of general application may be recognized, there are particular cases where it might be the best form of legalized control. Some disadvantages arising from the private ownership of lands are known to exist, and certain advantages to both the public and the user of the lands have been shown to result from public ownership of them. If a policy of public ownership of the land were temporarily or permanently followed, the most easily applied system of control for small areas of public lands scattered among large areas of privately owned lands would doubtless be a properly restricted leasing system. The regions to which this method would best apply are now not very numerous; they are to be found mostly in the railroad land-grant strips. The area of land which could be handled best in that way, though amounting to hundreds of thousands of acres, or possibly a few millions, forms a relatively small percentage of the land that needs a control system of some kind. Such lands could be most quickly transferred to private owners by selling them.

The same disadvantage that lies in a policy of unlimited sale is also found, to a less degree, in a leasing policy, i. e., the men who have most money have advantages over poorer men, unless restrictions be placed upon the amount of land one operator may lease. And it is almost impossible to include such limits in the law itself; they must be determined locally and temporarily upon the merits of the particular case.

Under existing conditions, any system of leasing must be so hedged about by restrictions and limitations in order that it may be fair to all, and the administrative authority must have such large discretionary powers in order that the law may be interpreted with sufficient elasticity to fit the varied conditions of location and time, that such a system is really nothing but a permit system. But the converse is also true. After the desirable classification of the land has been learned by experience and its subdivision into proper-sized units has been accomplished and the users have received long-time permits, the permit system as applied to such conditions is little if any different from a restricted leasing system.

The permit system has the advantage in that it is suited to present conditions and automatically changes into the other form as conditions warrant, while a leasing system that is adjusted to the present conditions is one in name only.

Consolidation of scattered holdings.—Consolidation by the method of exchange has been proposed, privately owned land to be traded for public land of equal value, so as to bring together lands of similar

tenure into bodies of considerable size. Within the boundaries of the large railroad land grants, in particular, this method may be of use. In such areas the odd-numbered sections of each township have been granted to the railroad company, resulting in a checker-board arrangement of the privately owned lands, which is discussed on page 20. Such consolidation would make the administration of the public lands much easier, and at the same time make possible the fencing of privately owned lands in bodies large enough for profitable use.

While such a policy would benefit all parties concerned, the areas to which it could be applied represent but a small part of the whole region for which a change in land policy is necessary. These land-grant areas contain many millions of acres, but the total area of the arid grazing region is many times more; and while the consolidation would be beneficial at once to the privately owned lands, further legislation would still be necessary for regulating the use of the public lands. The only advantage gained for them would be that any new laws made for the administration of the public lands would be easier to apply on a few large areas than upon very numerous scattered small ones—amounting, as they do now, to thousands of sections.

It is probable that in the present state of tenure and development very few of the private owners would wish to enter upon such a wholesale trading operation. Their lands are the better lands, for various reasons; the watering places are on their lands, and their businesses are localized about those watering places. They would much prefer a system by means of which they could obtain legal right to use the interspersed sections along with their own land.

Wherever all the land in a series of townships belongs to the railroad, the State, and the Federal Government in the ordinary checker-board arrangement, exchanges on a township basis might be arranged, though even here it would not be simple, and lessees of either State or railroad lands would suffer inconveniences and have difficulties in settlement of the relative values of watering places.

Notwithstanding all such difficulties, the method would be a perfectly fair one in certain regions and is recommended for such regions. The use of lieu land scrip in such transactions should be avoided.

Transfer of the remaining public lands to the several States.—Many efforts have been made to transfer the public lands to the States, but there is little probability that such attempts will ever be successful, because the people generally, both in the separate States where there is some public land and in States that have none, are strongly opposed to this method of disposal.

That States can make and operate lease laws that produce better results than our present Federal laws accomplish has already been noted in the case of Texas. That they frequently do make laws that may be temporarily beneficial but very unwise in the long run, may

be shown for most of the older States, by the disposal they have made of their school lands.

There is no doubt that in most States the lands would be allotted to users in some way or other in a very short time, if their disposition were transferred to the various State land departments. If the distribution of the land were the only desideratum, this method would probably accomplish the end more quickly than any other proposed. And, if the proposal could be called a policy, the rapidity with which the land might be disposed of would still be an argument against rather than in its favor, since it is important that the present adjustment of the business be changed very gradually and with the good of the greatest number as the controlling principle. State management would also result in great diversity of managerial policy. For such reasons it is believed that Federal authorities are in a much better position to control wisely.

As a legislative policy for the management of our remaining public lands this proposal can hardly have great weight, since it would merely avoid the question at issue—not solve it. If the land were transferred to the States for administration it would be as necessary for their officials to formulate a policy as it is now desirable that the Federal Government should make improvements in its existing policy. What is wanted is a policy of management and not a transfer of responsibility.

Adaptation of the permit system.—The permit system of control of the grazing lands would often differ very little from a leasing system, but it has several advantages over that system, not the least of which is its flexibility. The essential difference between them is that under the permit system a man receives a permit to graze a definite number of animals for a definite period of time on certain specified lands, with priority right to consideration for renewal at a future time, while under the other system a man gets the use of a definite number of selected acres of land for a definite period, usually also with priority consideration for renewal. The one plan determines the number of animals and the authorities take the responsibility of estimating the amount of land necessary to care for them. In the second case the user leases a specified piece of land and adjusts his stock to the feed produced thereon. At first sight there is no difference in the effect, but there are really two factors that are vitally important and over which sincere differences of opinion may arise and cause arguments in which differences of interest would interfere with correct judgment.

The amount of feed required for a given kind of animal differs very little, hence a uniform charge *per animal* for forage is fair to all and is easily applied; but a uniform charge for forage *per acre* of land is not at all equitable because the forage produced by different acres is

often very different both in quality and in quantity. Adjustment of stock to area by the permit system normally results in slight understocking of the range, if any mistake is made; while the lessee of an area is almost sure to overstock in order to be sure that he "gets his rent back." Especially is this true if his tenure of the land is for a short period only. Likewise is this true of a poorly-informed man who makes short-sighted plans. And it is very difficult to prove that he is really overstocking the range, until it shows deterioration, and then the harm has been done. For these reasons it is wiser to handle the range under permit.

Under certain conditions it is highly desirable to handle the grazing of a given area as a community pasture. This is particularly true in the vicinity of little towns where the owners of land adjacent to the grazing lands each have a few head of stock that need pasture. The permit system is easily adapted to such conditions, while a leasing system is difficult to adjust.

Where scattered bodies of land too small for separate use belonging to one owner are mixed with similar scattered areas belonging to one or more other owners, it is often advisable to use the land as a community pasture. Such an adjustment may be brought about by pooling the use and adjusting charges on the basis of the number of animals grazed and prorating expenses on the basis of tenure. If a part of the land is still Government land it might be leased to the owners, either separately or as a group, leaving them to determine its use and prorate the fees. The same result can be obtained by granting a permit for the grazing of a certain number of animals upon the land, but this method automatically regulates the rate of stocking to the grazing capacity of the land.

Neither the permit system nor the leasehold system is incompatible with the State governments receiving a share of the rents equivalent to the taxes which would be collected on such land if it were in private ownership.

The permit system need not interfere with a proper application of the homestead laws. It might temporarily delay the occupation of small areas of land suitable for crops, pending the demonstration that the land was of this character.

The right to prospect for and acquire mineral holdings might easily be granted also, without in any way interfering with the administration of the grazing lands.

That the remaining public arid grazing land should be added to the national forests has been suggested in many places by men who are now using the open grazing lands and are acquainted with the methods of control of grazing that are practiced in these forests. Many requests for such changes come to the Forest Service officials. In fact, it has happened that men who were very anxious to have the

land they had been using taken out of the national forests when these forests were first established and whose requests were granted, have since become just as anxious to have these same lands restored to the forests in order that they might benefit by the very system of control that was originally feared. Such a procedure would merely be the equivalent of extending the system now in use in the forests to such lands.

In the opinion of the writer there is good reason for the inauguration of a system of control of the arid grazing lands closely similar to that in use in the national forests; but to include unforested grazing lands within these forests in order to establish such a system on the arid grazing lands would give rise to just criticism, since these forests are primarily forested areas, while the arid grazing lands are not forest lands, and never will be. The argument that areas of unforested lands now do occur in places in the national forests, is only an argument for their elimination where possible, instead of for the introduction of others.

Any sort of permit system makes it necessary for capable officials to determine with reasonable accuracy the grazing capacity of a large region and formulate a plan for the region during a given season before they can begin to allot animals to specific areas. They must know the preferences of the stockmen, the possible uses of the different parts of the grazing area, its fitness for different kinds of animals, and many other details of its possible adaptations to use. All these details must be known before any fair and at the same time economic allotment of stock can be made. Hence this system leads to a careful consideration of a large region with a view to its best management. The leasing system usually lacks this characteristic.

If the grand divisions of the grazing region were made so as to include areas suited to a single type or complementary types of business, the management would become a simpler problem and there would be less probability of serious conflict of interests arising. It is probable, however, that district boundaries should ordinarily correspond with State lines so that rulings as to control would not meet the difficulty of adjustment to more than one set of State laws.

Perhaps as strong an argument as any in favor of this system of control lies in the fact that it can be applied in any place, whatever state of development the business may be in at the time of its application. The system can be made to fit where the business is highly organized and specialized or with equal ease where the reverse is true. It will work where the holdings are large or where they are small. It requires no radical change in general management and yet makes gradual adjustments not only possible, but by its very nature tends to improve the organization of the business of the region. It is a restraining influence upon aggressively domineering men and an

encouragement to weaker or less fortunately placed individuals. In operation it automatically makes for the gradual reduction in size of the excessively large holdings that in the early stages of development are necessary, without disturbing the production of the area and without injustice to the equities of the large holders. The attitude of rational constructiveness is a basic factor of the system.

Any other plan that has been proposed merely fixes the status of the lands. None of them anticipates a development of the industry or the improvement of the range. The permit plan would immediately put into effect a system of control that would meet the present requirements of the industry and would keep in view the future development of the business as well as the conservation of the range upon which the industry depends.

It may be said in further support and recommendation of this plan that an expression of it has been in increasingly successful and satisfactory operation on the national forests for a number of years. In building up the system, the Forest Service has met and solved many of the difficult problems that have arisen, and now has a force of trained men who are capable of applying the system and of training others to apply it. It does not of necessity follow that all the details of their adaptation of the plan should be slavishly copied, but their experience and judgment as expressed in their practices should certainly receive careful consideration.[18]

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[18] For those who are not acquainted with the principal features of the system as applied, the following note is appended (The details of the rulings may be found in the latest Use Book, issued by the Forest Service):

The method of handling the National Forest ranges for the grazing of live stock is based upon the permit, rather than the acreage system, as being more flexible and satisfactory. Permits are issued upon applications which give full information as to the owner's status as a stockman. He must own the stock absolutely in his own name. He must own land on which forage is produced for the feeding of the animals under permit, when off the forest ranges. Leased lands are not considered as a basis for a permit. Permits are issued for periods of from one to five years and are not transferable. If a permittee desires to sell his stock and the lands connected with their use, the purchaser can obtain from the seller a waiver to the United States of his grazing preference, which entitles the purchaser to a renewal of the permit for the rest of the grazing season. If the purchaser is properly qualified a permit will be issued to him personally the next season. The signer of a waiver can not again obtain a permit for a period of three years unless there is surplus range not needed by other applicants. With each permit sufficient range is allotted to graze the number of animals allowed.

With cattle, the ranges are generally used in common. With sheep, each permittee receives a definite allotment upon which his sheep must be held. Cattle, not being under control of herders, can not be kept closely upon their allotted ranges, but, as far as possible, this is required by the terms of the permit.

If owners have ranges on the public domain adjoining the forests and their stock can not well be restrained from finding their way upon the forests, "On and off" permits are issued which cover the whole number of animals that may, at any one time, be upon the forest, but payment is required for only the average number that graze.

Drift fences are allowed at points where they seem advisable in order to restrain cattle from drifting away from their proper ranges. Pastures of reasonable size are granted permittees for the purpose of holding steers and stock for sale, holding saddle and work horses, and for use in breeding and weaning. Drift fences are not charged for, but individual pastures are, the charge being by the acre and based upon the value of the lands for such uses.

To prevent monopoly of the ranges, certain maximum limits are established for each forest above which no individual firm or corporation may receive a permit. Protective limits are also established below which no permit will be reduced to make room for new men.

It should thus be clear that while the permit system is perhaps the best single system that has so far been devised for the management of these arid grazing lands, not the least of its advantages is that it does not necessarily interfere with the application of the homestead policy, the consolidation plan, or a lease law in the regions where these methods are desirable.

It is not intended to suggest or assume that a permit system is flawless. It has certain well-known disadvantages. Not the least important of these is the necessity of a complex supervisory authority. In operation, more or less friction between officials and permittees will occur because of differences of judgment as to the use of the lands. This difficulty can only be minimized, not obviated. Organization of the stockmen and the creation of advisory boards for consultation with the administrative authorities have gone far toward reducing such friction in the National Forests.

In administering the permit system in the National Forests it was found necessary, for a long time, to issue annual permits to stockmen in order that the necessary adjustments of numbers of animals to available feed might be made each year, and the greatest number of permittees be thus accommodated. Not until after the stock business of a region becomes tolerably well stabilized and the use holdings definitely located, is it possible to lengthen the period for which permit is issued. Even then the long-term permit must be hedged about by various restrictions and limitations that make it look like a doubtful asset to the permittee. These necessary limitations of the system usually cause permittees to delay construction of all permanent improvements because they are not certain that they will profit by such improvements enough to warrant the expenses involved. A policy of absorption by the Government of the property rights in such permanent improvements also causes the permittees to avoid or delay making such improvements. This policy doubtless is derived from the custom of assuming that all permanent improvements necessarily belong to the owner of the land upon which they may be made.

These difficulties, however, are not insurmountable. An annual permit becomes the equivalent of a long-term permit if it may be renewed each year for an indefinite period. Restrictions that limit one to the best kind of use are restrictions in name only, even if they do appear quite portentous when written into a contract. Nor is it necessary that improvements put upon the land should thereafter be permanently attached to the land. Many forms of lease give the tenant right to remove improvements made by himself from the land of his landlord. In certain of the Australian colonies, improvements are recognized as belonging to the lessee, and when made on Crown lands the improvements may be removed, sold to the next tenant,

or under certain conditions the colonial government itself buys the improvements at reasonable valuation.

It should be recognized that the permit system of management is but temporary, being adapted especially to the present status of the range business. It is believed that under a properly limited use of this system the tenure question will gradually solve itself with the minimum disturbance to the productivity of the land. In other words, if properly restricted legal right to the control of the land now used be given the present users, carrying with it the right to fence wherever they wish to do so, and if suitable protection of their property rights in all improvements made by them be assured, a temporary subdivision of the land would result which would give the best present adjustment. Periodic readjustments should be provided for. Such an arrangement would not keep out the properly qualified homesteader, but would tend to restrict him to areas on which he could hope to succeed in his farming operations, without the losses that now occur. One of the best recommendations for such a system is found in the fact that its establishment does not necessarily interfere with the subsequent disposal of the lands under some other plan if a better plan were evolved.

Assuming that the lands should pass to private ownership, with a permit system in effective operation, consolidation by exchange or sale would be effective in regions where small areas of public land are scattered among large areas of private lands. Where thousands of acres of land so distributed are held by corporations or individuals, and it would not be wise to allow them to purchase more, the exchange method would apply. For the consolidation of holdings of reasonable size, sale of the scattered parcels of public land would doubtless be the most convenient method of disposal. If public ownership of the land be retained, for any reason whatsoever, such scattered small acreages of land could be managed most easily under restricted leases. Wherever development has brought about an adjustment that approximates what is desirable in the sizes of holdings, a restricted lease law would apply. Under such conditions it would have the advantage of costing less than any other form of governmental administration and would retain sufficient supervisory control to insure development.

At present, most of the remaining unreserved Government lands occur in large areas, with scattered State and private holdings interspersed. Many of the use holdings are so large that subdivision is now or will become necessary to assure the best ultimate use. For lands in this condition the permit system is believed to be the best form of management. It is evident that the methods of exchange and of sale have very restricted application, and should be used with great care. Such application might easily be made within an area

controlled under the permit system if discretionary powers were given administrative officials.

As has been said, where a lease would apply best the long-period permit is not essentially different from a restricted lease. The permit system places supervisory powers in the hands of officials, who thereby become responsible for the proper conservation and development of the lands, and makes necessary the selection of men who have this broad outlook. Its administration keeps them constantly in close touch with users of the land. This possibility of ready adaptation to various conditions is one of the greatest advantages of the system.

Not yet thoroughly appreciated by all who have studied the subject is the fact that these various policies not only do not conflict, but are more or less complementary. It is not proposed that any one be adopted in lieu of all the others, but that the value of each in its place be recognized and that each be properly applied. As has been said, the one which may be made to apply most generally at present is the permit system, and the way in which it can be most properly localized and restricted in use is by the passage of a law similar to that introduced in the first session of the Fifty-sixth Congress by Senator King (S. 1516), which authorizes the President to establish "grazing commons." In its original form that bill would extend the grazing system now in use in the national forests to lands to be designated by presidential proclamation. Some modifications of existing practices which such a law would establish would be necessary to give the degree of adaptability which has just been described. The argument presented here is not in behalf of any particular permit system, but is an attempt to present the relative merits of all proposed methods.

CONCLUSION.

In conclusion, it can not be gainsaid (1) that the arid grazing lands are today mostly overstocked and deteriorating under the present form of use; (2) that they are being operated at a low standard of productivity because of poor organization; and (3) that this form of use is brought about by our land laws. It hardly need be stated that this sort of use ought to be stopped and that it is high time we changed these land laws. Though improvement in organization of the range stock raising business does not necessarily follow as a result of a change of methods of tenure, improvement is absolutely impossible under existing laws.

Students of our national development have pointed out that in the occupation and conquest of our country we have passed through two stages of development and are now just becoming aware as a nation that we have reached a third stage. "During the first stage individual enterprise for personal and family benefit was dominant and conquered the wilderness. The idea of husbanding natural resources received practically no thought. The next stage was one

of collective enterprise, for the benefit of communities or of individuals forming them. During this stage great internal developments took place and new cities and new States were erected. This was also the stage during which great monopolies, largely based on control of natural resources, etc., began to develop, with the characteristics of the first stage still more or less dominant. The third stage upon which we are now entered is one in which enterprise is largely collective and cooperative and should be directed toward the larger benefit of communities and the people generally, however difficult it is to realize this fully with our past inheritance. Larger social interests, however, are being gradually realized. Conservation is the resounding note. A difficulty is that under this new ideal, which must be pronounced essentially democratic in spirit, there are still persisting those individualistic elements so strongly encouraged during past decades of national development. Furthermore, the frontier, in some senses, still exists, and Western States and Territories, including Alaska with its remarkable resources, still offer tremendous incentive for the expression of the same characteristics observed in the past." [19]

In no place has this conflict of individual with group interest been shown more strongly than in the national forests and on the open ranges of the West, where pioneer conditions have obtained and the weight of the struggle to utilize natural resources and organize a productive business has fallen upon the individual. At the same time the general Government, with the sanction of the great majority of the people, has insisted that this development be of such a character as to protect the interests of society instead of that kind of development which will bring the greatest financial benefit to individuals.

In the national forests, development has now progressed to a stage where even the most strenuous individualists are beginning to recognize that the present form of management is in many ways superior to that which they wished to perpetuate. The extension of the national forest plan is here proposed for the grazing ranges, and public opinion, so far as it is definitely formed, is in favor of this plan. The two outstanding results of the application of this system of control are that, while production is in no way reduced, the distribution of the benefits to be gained is more equable and most of the waste is avoided.

APPENDICES.

METHOD OF ALIENATING LANDS.

Following are some tables which show in condensed form the statutory provisions relating (1) to the disposal of lands in the Western States, (2) to the Atlantic & Pacific Railroad land grant, (3) to lieu land selections, and (4) to Indian allotments.

This summary will assist in understanding the details upon which the existing conditions rest.

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[19] Hill, Robert Tudor, "The Public Domain and Democracy," p. 217.

A.—*Principal United States statutes relating to disposition of public lands in the Western States.*

Act.	Designation.	Date.	Principal provisions.			
			Maximum acreage.	Application.	Requirements.	General.
Homestead	Revised Statutes: Secs. 2289–2302. Secs. 2304, 2305, 2308, 2372.	May 20, 1862. Several later dates.	160	Unappropriated public lands.	Five years' residence, cultivation. Amendment permits final proof at end of three years.	Commuting privilege after 14 months.
Desert land	19 Stat., 377. 26 Stat., 1096. 35 Stat., 52. 36 Stat., 867. 37 Stat., 106. 38 Stat., 712. 38 Stat., 1161.	Mar. 3, 1877. Mar. 3, 1891. Mar. 28, 1908. June 25, 1910. Apr. 30, 1912. Sept. 5, 1914. Mar. 4, 1915.	320	Unappropriated desert lands.	Payment of 25 cents per acre, expenditure of at least $3 per acre in improvements, and cultivation of one-eighth of area.	Residence not required.
Timber and stone	20 Stat., 89. 26 Stat., 1096. 27 Stat., 348.	June 3, 1878. Mar. 3, 1891. Aug. 4, 1892.	160	Lands valuable chiefly for timber or stone, but unfit for agriculture—in Western States.	Payment of purchase price—not less than $2.50 per acre.	Act repealed as far as timber lands are concerned by act of Mar. 3, 1891.
Reclamation act	Revised Stat., 32 Stat., 358.	June 17, 1902	Unit sufficient to support family, not more than 160 acres.	Irrigable lands	Usual homestead requirements.	No commutation privileges.
Kinkaid	33 Stat., 547. 35 Stat., 465.	Apr. 28, 1904. May 29, 1908.	640	Nonirrigable lands in western Nebraska.	Residence; improvement and cultivation.	No commutation privileges; final proof not before five years after first entry.
Enlarged homestead	35 Stat., 639. 37 Stat., 132. 37 Stat., 666. 38 Stat., 953. 38 Stat., 956. 38 Stat., 1162.	Feb. 19, 1909. June 13, 1912. Feb. 11, 1913. Mar. 3, 1915. Mar. 3, 1915. Mar. 4, 1915.	320	Nonirrigable, nontimbered lands.	Cultivation of at least one-sixteenth of area, residence.	No commutation privileges; proof to be made between fifth and seventh years. Before entry, lands must be classified.
Homesteads within national forests.	34 Stat., 233	June 11, 1906	160	Agricultural lands within national forests.	Residence and cultivation.	
Stock-raising homesteads.	39 Stat., 362	Dec. 29, 1916	640	Unappropriated lands principally suited for grazing and of such character that 640 acres are reasonably required to support a family.	Permanent improvements of the value of at least $1.25 per acre, one-half to be expended within three years after date of entry.	No commutation privileges.

B.—*Principal United States statutes relating to Atlantic-Pacific Railroad Company's land grant.*

Act.	Designation.	Date.	Principal provisions.
Grant	14 Stat., 292	July 27, 1866	Alternate sections over a strip on either side of the railroad to be constructed, 40 miles wide through territories and 20 miles wide through States, lieu selections in a strip not more than 10 miles beyond the limits of the original grant. (The 40-mile strip on either side applied to lands in Arizona and New Mexico.)
Forfeiture	24 Stat., 123	July 6, 1886	Grant of lands except right of way forfeited adjacent to uncompleted portion of the road. (This forfeiture applied in New Mexico to the lands east of Albuquerque. The grant remained valid west of Albuquerque in New Mexico and across Arizona.)

C.—*Principal United States statutes relating to lieu selections of lands in the Southwest.*

Act.	Designation.	Date.	Principal provisions.
Forest lieu selections	30 Stat., 36	June 4, 1897	Private claims or patented lands within a National Forest may be relinquished and corresponding area selected in exchange.
	33 Stat., 1264	Mar. 3, 1905	Repealed above act in so far as it applied to lands within National Forests.
Relief of Indians on railroad lands.	37 Stat., 1007	Mar. 4, 1913	Secretary of Interior may request of present claimant under any railroad land grant a relinquishment of any lands in Arizona or New Mexico passing under the grant, shown to have been occupied for five years or more by an Indian entitled to receive the tract in allotment except for the grant to the railroad company. Upon such relinquishment the claimant may select lieu lands and the original tract shall become available for allotment.

D.—*Principal United States statutes relating to Indian homesteads, allotments, and reservations as applicable to the Southwest.*

Act.	Designation.	Date.	Principal provisions.
Indian homesteads	18 Stat., 420	Mar. 3, 1875	Any Indian born in United States, who has arrived at 21 years, and has abandoned his tribal relations, is entitled to the benefits of the homestead acts.
	23 Stat., 9698	July 4, 1884	All patents for Indian homesteads shall be held in trust by the United States for a period of 25 years and then shall be conveyed in fee, free of all incumbrance.
Allotments	24 Stat., 388	Feb. 8, 1887	President authorized to allot land to Indians on reservations as follows:

	Agricultural land.	Grazing land.
To each head of family	160	320
To each single person over 18 years of age	80	160
To each orphan child under 18 years of age	80	160

D.—*Principal United States statutes relating to Indian homesteads, allotments, and reservations as applicable to the Southwest*—Continued.

Act.	Designation.	Date.	Principal provisions.
Allotments	24 Stat., 388	Feb. 8, 1887	Indians not residing on reservation, or for whose tribe no reservation has been provided, who shall make settlement upon any surveyed or unsurveyed lands of the United States not otherwise appropriated shall be entitled to same as allotments. In case lands are unsurveyed, grants shall be adjusted upon the survey of the lands so as to conform thereto. Upon completion of allotments and issuance of patents all Indians shall be considered full citizens of the United States. Provision for purchase by U. S. from Indians of lands not needed by them; such lands to be used for sole purpose of securing homes to actual settlers.
	25 Stat., 612	Oct. 19, 1888	Indians holding patents to land on reservations may in discretion of Secretary of Interior surrender such patents and select other lands in lieu thereof.[1]
	30 Stat., 83	June 7, 1897	If by reason of age, disability or inability, any allottee of Indian lands can not personally or with benefit to himself occupy or improve his allotment, it may be leased for farming or grazing for a term not exceeding three years.

[1] Indians with lands outside of reservations apparently could not dispose of them until patent issues, without special act of Congress.

LEGISLATION PROPOSED AT ONE TIME OR ANOTHER.

Following is a tabulated list of the principal bills that have been proposed at one time or another, with a view to giving better control of the arid grazing lands. Their more important provisions are shown. A table showing the provisions of some of the more important systems of leasing grazing lands that are in successful operation is also given.

E.—*Principal bills introduced in Congress relating to disposal of public lands other than by homesteading.*

Designation.	Date introduced.	Author.	Principal provisions.
H. R. 5061	Jan. 3, 1900	Mr. Stephens.	Purpose, to provide for leasing public lands for grazing purposes. Lands to be leased by Commissioner of General Land Office; preference to be given bona fide settlers for 90 days—then to be leased to highest bidder. Land with permanent water to be leased for maximum period of 5 years at not less than 3 cents per acre. Land without permanent water to be leased for maximum period of 10 years at not less than 2 cents per acre. Lease must be for personal use of lessee; no lease to exceed 2 sections of watered land and 6 sections of dry grazing land. Encouragement to be given water development by option on grazing privileges for 90-day period. Persons leasing to have right to purchase lands leased; improvements to be considered personal property. Lands suitable for agriculture may be withheld from lease.
H. R. 13391 Fifty-sixth Congress.	Jan. 8, 1901	Mr. King	All vacant public lands and water rights thereto to be ceded to Western States in which such lands are located, States not to lease or dispose of such lands in larger tracts than 320 acres to any one person or association.

E.—*Principal bills introduced in Congress relating to disposal of public lands other than by homesteading*—Continued.

Designation.	Date introduced.	Author.	Principal provisions.
H. R. 14108 Fifty-seventh Congress, first session.	Apr. 30, 1902	Mr. Lacey....	Purpose, to secure use and development of grazing lands by small stockmen. Act to be administered by Secretary of Interior. Grazing lands to be leased, subject to all lawful entry, for maximum period of 5 years to individuals only, and for their personal use in tracts of not more than 3,200 acres; the leased land not to exceed ten times the area of land owned by the applicant. Where demand exceeds supply land is to be apportioned. Land to be classified and charges to vary according to value of grazing. Lessee to have privilege of fencing. Lands not applied for may continue to be used as in the past.
S. 7618 Fifty-ninth Congress, second session.	Jan. 8, 1907	Mr. Burkett...	Purpose, to regulate grazing upon public grazing lands, President to set aside grazing districts to be administered by Secretary of Agriculture. All stock using such districts to be charged a reasonable fee as on forests. Lands to remain subject to homestead entry, but latter not to give grazing privileges except when made under laws requiring cultivation and agricultural use; all range improvements on lands subsequently homesteaded must be paid for. Leased lands not to be affected by subsequent appropriation except as to land actually appropriated, until end of current annual grazing period. Percentage of grazing receipts to be turned over to States.
S. 5431 Sixtieth Congress, first session.	Feb. 18, 1908	Mr. Curtis.....	Purpose and provisions practically the same as in the Burkett bill (S. 7618 above), but with a specific provision for local control by an advisory board representing stockmen using the range who shall assist the representative of the Department of Agriculture. Disputes to be referred to the Secretary of Agriculture for adjustment.
S. 3462 Sixty-second Congress, second session.	Dec. 7, 1911	Mr. La Follette.	Practically identical with the provisions of the Curtis bill. (See S. 5431 above.)
H. R. 10539 Sixty-third Congress, second session.	1913.....	Mr. Kent.....	Purpose, to regulate and improve grazing on the public lands of the United States. President to be authorized to establish grazing districts which shall be administered by the Secretary of Agriculture. Grazing to be authorized by permits for period not to exceed 10 years with right to fence. Preference to be given homesteaders and present users. Fees to be based upon grazing value of land. Homesteading not to be restricted. In other respects the bill is practically the same as the Curtis bill. (See S. 5431 above.)
S. 5067 Sixty-fifth Congress, third session.	Dec. 3, 1918	Mr. Jones.....	Purpose to extend the rights of stock-raising homesteaders. An entryman under stock-raising homestead Act may lease .... acres of suitable vacant contiguous public land for not to exceed 5 years with the right to purchase such lands leased after securing patent to his homestead.
S. 1516 Sixty-sixth Congress, first session.	June 6, 1919	Mr. King.....	Purpose, to regulate and improve grazing on the public lands. President to be authorized to establish grazing commons which shall be administered by the Secretary of Agriculture.

F.—*Examples of land-leasing systems in successful operation.*

Where applied.	Tenure of lands.	Period of lease.	Size of unit.	Principal provisions.
Australia[1]	State	14 to 42 years	Area sufficient to support family.	Classification of lands and allotment by Government Board of Commissioners; stockmen usually required to fence and otherwise improve their holdings.
Texas[2]	State	5 and 10 years	Protective limit of leasehold, 10 sections of grazing land; no maximum limit.	Lands leased subject to sale of agricultural lands during term of lease in units of not to exceed 4 sections. Grazing lands not subject to sale during lease. New settlers may lease portion of large leasehold, provided such leases will not reduce the size of the leashold to less than 10 sections.
New Zealand[3]	State	21 years	Small grazing runs 5,000 to 20,000 acres. Pastoral runs not greater in extent than will carry 20,000 sheep or 4,000 cattle.	Large private holdings were purchased by the State and leased to settlers. Revenues loaned to settlers and stockmen. Lands classified: Those suitable exclusively for pasturage are leased; those suitable for agriculture may be acquired through purchase or leased in perpetuity. Improvements on leased land are considered property of lessee.
National Forests[4]	United States	Permits for 1 and 5 years.	Size determined by prior use; gradually adjusted to meet needs of new settlers.	Charges based upon a per capita basis; areas allotted according to grazing capacity; preference given to citizens of the United States, and small owners who own and reside on improved ranch property and are dependent on the National Forests for range, then old users and larger owners. Maximum limits fixed to prevent monopoly and protective limits set to prevent reduction below a reasonable number of stock.

[1] See Land Laws of Australian Colonies.
[2] See Summary by F. V. Coville, Senate Doc. 189, Fifty-eighth Congress, third session, p. 26, 1905.
[3] See Land Laws of New Zealand.
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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 1002

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H. C. TAYLOR, Chief

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OPEN TYPES OF PUBLIC MARKETS.

By McFall Kerbey, *Formerly in Charge of City Marketing Investigations.*

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INTRODUCTION.

There are several types of public markets in the United States for the sale of food products. Some farmers may and probably do sell through each of the types, but the typical "farmers' market" in most sections of the country is of the so-called open type, which is held either along street curbs or on tracts of ground especially set aside for market purposes. Markets of the latter type though protected by sheds are still considered open markets. In common usage the term "open market" refers to all markets other than those consisting of stalls, booths, or store spaces housed in buildings. The latter are most commonly referred to as "inclosed markets." In this bulletin the term "open markets" will be used as including "curb markets" and "shed-protected markets," and as practically synonymous with "farmers' markets" and "producers' markets."

A public market differs radically from a store, shop, or group of shops under one ownership. In such stores and shops the person owning or controlling the agency also owns and controls the goods sold. In public markets, on the other hand, the agency—that is, the market—and the actual selling of the goods are in different hands. A "market" in the sense meant in this publication is merely a place in which and a group of conditions under which sales may be made by numerous owners of goods. The market establishment, in other

words, merely furnishes facilities for sales, and when utilized constitutes a group of independent dealers.

Open public markets are the modern representatives of what were probably the first pieces of commercial machinery forged by man—the trading post, the bazaar, and the seasonal market fair. In Great Britain and Ireland public markets, developing from the market fairs, early came to occupy a position of importance in the distribution of agricultural produce, and it was only natural that the market ideas and practices of those countries should be brought over by British settlers, who made up a large part of the early population of this country. The survival to-day of names such as "Market Street" and "Market Square" in the cities of New England and those of other Atlantic Coast States bears testimony to the important part which public markets played in the early city life of the United States.

Since public markets are of primitive origin, and since present conditions of life are exceedingly complex, the question arises in some minds whether there is any place for such agencies in the modern distribution system. Public markets are certainly not ideal distribution agencies, but the same can be said truthfully about practically all distribution agencies in their existing forms. In regard to economic justification for public markets in the present day the investigations of the Bureau of Markets indicate that the following is the true situation. Taking into consideration practical alternative agencies, existing customs and prejudices among both producers and consumers, and the seeming innate individualism of many farmers, public markets of appropriate types often solve local distribution problems in regard to fresh produce better than other existing agencies.

The fact that thriving public markets exist in many cities and towns demonstrates that such agencies are still popular with a considerable number of producers and consumers who feel that public markets best meet their needs. Some farmers, especially those operating on a relatively small scale, are reluctant to surrender possession of their products for sale on commission or even to sell outright to wholesalers when they know that the products probably will be resold immediately for a higher price. The question of the trustworthiness of available agencies also enters at times, and farmers feeling any doubt on this score, whether or not their doubts be well grounded, naturally prefer to carry their products under their own control as far as practicable along the channels of distribution. Large scale producers, on the other hand, being in a better position to select satisfactory agencies and to obtain desirable terms from them, and appreciating better, perhaps, the possible time-saving value

of division of labor in distribution, are more likely to prefer commercial or "middlemen" distribution agencies to the more direct agencies such as public markets.

Some consumers in nearly every walk of life decidedly prefer to purchase the fresh produce which their families consume as nearly as possible directly from the producers. Such consumers usually prefer, if it is possible, to make their purchases at a public market rather than from producers who peddle from door to door, since it is possible in the former case to choose from a larger assortment and to consider comparative values. Similarly, as between individual shops and public markets, consumers who prefer to buy at the latter state that the markets afford greater opportunities for choice and for making a comparison of values, and that in general they feel that they obtain greater satisfaction for the money expended.

FUNCTION OF PUBLIC MARKETS.

From what has been said in regard to the economic justification of public markets it is apparent that their function is not to replace all other agencies in the distribution of fresh produce but only to supplement them where conditions are such as to make supplemental agencies desirable and their operation practicable. Diverse conditions are encountered in the production of food products, and a variety of forces and factors make up the demand for such supplies. It is natural, therefore, that in the machinery of distribution, which exists to meet the needs of both producers and consumers, there are various agencies. Public markets constitute merely one type of agency. Originally under simpler conditions of production and demand they were of great general importance; at present, under more complex conditions they are of relatively less importance; but they are of considerable importance, nevertheless, to large groups of producers and consumers in many localities, and under such circumstances may well be maintained to meet the needs of such groups.

Where the establishment of public markets is proposed, retail grocers often oppose the plan with the statement that an effort is being made to displace them as distributors of farm produce. As a matter of fact, the establishment of public markets seldom injures grocers and often builds up their trade in supplies bringing greater profit than farm products. If grocers realized that public markets are merely supplemental distribution agencies, and that because of the demand of many consumers for service, markets can not monopolize the trade in farm produce, much futile opposition to markets would be avoided.

From the point of view of the producer the function of public markets is to furnish an easily accessible place where there is a considerable demand for his goods and where at relatively slight ex-

pense he can personally conduct sales. A properly operated public market makes possible the free interaction of the forces of supply and demand and places the operation of such forces more or less under the observation of the producer, and so furnishes one of the best possible opportunities for arrival at a fair "market price." When producers peddle their wares from house to house or store to store their opportunities to judge the fairness of prices offered are obviously poorer than when they sell on a properly operated public market.

From the point of view of consumers who wish to patronize public markets their function, when properly operated, is to make available for choice larger quantities of fresher produce than can be found at ordinary stores, at lower prices, and in some cases under more satisfactory sanitary conditions. In addition to looking to markets to furnish lower prices themselves, consumers also see in such agencies a force which tends to bring about an indirect reduction of prices throughout the community by furnishing an active competition.

From the point of view of the community, properly operated public markets perform more fundamental functions in addition to those mentioned. By furnishing trustworthy outlets for miscellaneous food products they tend to encourage the farmers of the vicinity to produce more; they tend to help solve the city's problem of making available an adequate food supply at reasonable cost, so as to keep at home a greater proportion of the money spent by the citizens for food; and in general they tend to increase prosperity and improve living conditions, both in the city and in its immediate trade territory.

RETAIL AND WHOLESALE MARKETS.

Reference has been made to open markets as distinguished from inclosed markets. Such open markets may be for the purpose of sales at retail, at wholesale, or by both methods. On the other hand, inclosed public markets in the United States are almost always retail markets.

Open retail markets constitute the simplest and least expensively operated of all types of public markets. In its simplest form a market of this type may be merely a designated length of curb, a section of a broad street, or a vacant lot, where under slight supervision farmers may group their wagons and sell to consumers. In its highest development such a market may consist of a paved tract with raised walks covered with substantial sheds to protect teams, wares, buyers, and sellers from the weather. The sheds may even be of a type which in periods of inclement weather may, by the operation of rolling doors, be practically made into inclosed buildings. A few cities have erected sheds along street curbs for the pro-

tection of open markets, but for the most part curb markets are unprotected and sheds are constructed only in markets situated on special market tracts.

The essential feature of a retail market is, of course, the restriction of purchases to consumers as distinguished from dealers. Such a market, if it is a "producers' market," furnishes an opportunity for direct dealing between producers and consumers. Open retail markets may also admit hucksters or wagon and push-cart peddlers as salesmen. Such dealers are usually admitted under certain restrictions.

In a few large cities along certain street curbs open retail markets exist in which the salesmen are entirely nonproducers. For the most part, however, open retail markets are producers' markets or predominantly so.

Open wholesale markets, like the retail markets, may be situated along curbs, in the center of broad streets, or on special market property. Such markets exist for the convenience of producers of large quantities of farm produce who desire to sell in large quantities, and for the convenience of grocers, hucksters, hotels, restaurants, and other purchasers who desire to buy in large quantities. Wholesale markets, like the retail markets, may be unprotected or may be equipped with structures designed to facilitate trading.

While in many communities wholesale and retail public markets are maintained as separate institutions, in other communities combined wholesale and retail markets are operated. In some combination markets the two methods of trading proceed simultaneously, but in general it is considered the better practice to confine them to separate periods. In small communities where there is a danger that the small supplies available will be exhausted by wholesale purchasers, it sometimes becomes necessary, if the retail market is to be preserved, to have the earlier period devoted to retail trading. In larger cities, however, where neighboring production is more fully developed and where there is a more definite classification of large-scale and small-scale producers, the more normal arrangement is followed of setting aside the early morning hours for wholesale trading and the later morning hours for retail dealing.

OWNERSHIP AND CONTROL.

Open public markets may be further divided into subtypes on the basis of ownership and control. Open public markets of the several kinds already mentioned may thus be owned or controlled by municipalities, organizations or associations of producers, or commercial corporations.

The great majority of the open public markets in the United States are municipally owned. This would seem to indicate that

many municipalities recognize, whether consciously or unconsciously, the potential value of such markets to the community. In colonial times, when the villages and towns were intimately connected with the surrounding agricultural country and when their dependence on the farmers was more obvious than to-day, public markets were established as municipal institutions as a matter of course, and markets under any sort of private ownership were practically unknown. For the most part the few open markets under control of producers or other private persons or associations that exist to-day have been established where economic conditions made such agencies desirable but where municipalities failed to realize their obligations and opportunities indirectly to facilitate food production and distribution, or where, not content to have their public markets self-supporting, they sought to operate them as money-making enterprises.

Best practice among municipalities shows the proper conception of municipal public markets to be that they are agencies for facilitating and cheapening distribution, both directly and indirectly, and so benefiting both producers and consumers. Where this essential nature of municipal markets is recognized they are operated so as to produce an income that will meet all legitimate charges, including operating expenses, interest on investment, and proper sinking-fund charges, and no more. If small fees will bring in sufficient revenue to meet the legitimate charges referred to, such fees are charged. The difference between them and possible maximum rental returns is considered by the municipality as dividends to producers and consumers, appearing roughly in the former case as increases over prices offered to farmers by commercial agencies, and in the latter case as reductions under existing prices in stores or under higher prices that probably would prevail in such stores if the municipal markets did not exist. Municipalities fully awake to the real functions of a municipal market, seek, of course, through their methods of operation, to see to it that the difference between fees charged and possible maximum fees will not be absorbed wholly by sellers, with the result that there would be no savings to consumers. Every effort should be put forth to make the market function both as a direct source of good food products at somewhat reduced prices and as a city-wide governor of food prices. It would seem very difficult to justify the existence of municipal markets which are operated with little or no thought of stimulating production and facilitating distribution, or are operated frankly as mechanisms through which to collect additional taxes.

Where producers have felt the need of public markets, but have been unable to induce municipalities to operate such agencies properly or at all, they have in some instances organized and operated

markets of their own. Such markets may be operated by ordinary corporations, joint-stock companies, or nonprofit or cooperative associations. In practically all respects except ownership, producer-owned markets are comparable to the better municipal markets. They furnish, for the most part for a reasonable fee, the location and facilities for marketing and general supervision over operations, leaving the actual sales to the individual producers. In a few instances such producer-owned markets have assisted in the development of growers' exchanges which take care of sales for their members. The latter agencies, however, are obviously vitally different from public markets.

Open markets under the ownership and control of private persons or corporations composed of other than producers are in most cases frankly operated as commercial money-making enterprises. Only a few such markets exist, usually in cities in which neither the municipality nor the producers have established public markets or where existing public markets are inconveniently located, poorly operated, or are otherwise unsatisfactory. The fees charged for the use of space on privately owned commercial markets are naturally higher in most cases than fees on municipal or producer owned markets.

ESSENTIAL CONDITIONS FOR SUCCESSFUL OPEN MARKET.

Open public markets, especially the simpler kinds, are capable of more general establishment than inclosed markets. It can not be emphasized too strongly, however, that even the simplest type of market can not be established successfully in a haphazard way under chance circumstances. There are certain essential conditions, mostly economic, that must exist before a public market can be a success, and enthusiasm alone or a mere desire, however laudable and earnest, to reduce living costs will not take the place of such necessary conditions. Numerous communities have learned this lesson by bitter experience. Wherever successful public markets exist they have, consciously or unconsciously, been established and maintained in accordance with the essential conditions referred to.

In the first place the size of the city or town must be taken into consideration in relation to the type and kind of market proposed. Villages may be too small and cities too large for open public markets. In the former case the community is likely to be in close touch with the surrounding farming country, so that much produce is sold directly from farm to home. Many residents of villages also own neighboring farms and obtain supplies from them, and the custom of maintaining commodious home gardens is much commoner in villages than in larger towns. There is, therefore, in most small villages an insufficient demand to support even the simplest type of open market.

In very large cities, on the other hand, an active demand for open markets may exist in the congested sections, but the furnishing of the necessary supplies to such sections may be impracticable. Open farmers' markets are thus out of the question in certain sections of very large cities, because the areas of production are so far from those sections that it is unremunerative for farmers to haul their wares there. If such sections are to be provided with open markets, they must be markets of hucksters and pushcart vendors. It may be mentioned in passing that such congested sections of cities as those referred to above are often admirable locations for inclosed middleman markets.

Exceptions will exist, but in general even the simplest type of open retail market along a street curb can not be expected to succeed in towns of less than 10,000 to 12,000 population. It will usually be unwise to establish a substantial open retail market on a market tract in cities of less than 25,000 or 30,000 population unless the signal success of a curb market demonstrates that the situation is exceptionally favorable. Wholesale markets, even when combined with retail markets, are seldom found in cities of less than 40,000 population unless they are maintained largely for sales to outside buyers for shipment. The best developed wholesale markets are found in cities of well over 50,000 population, and it is also in the cities from this size upward that the most thriving open retail markets are found.

The size of a city alone, however, is only a rough indication of the practicability of establishing a certain type of market. A more accurate index is the probable number of people who can be depended upon to patronize the market. The proportion of a population which represents potential market customers will vary with nationality, local customs and prejudices, climatic conditions, and the like. It often happens, therefore, that a public market in one city receives heavier patronage than a similar market in a somewhat larger city. In estimating the number of potential customers of a public market consideration must be given also to existing agencies such as "green groceries," hucksters, and other agencies concerned in the distribution of farm products, and to what extent such agencies meet the needs of consumers.

Of equally fundamental importance with the subject of demand in determining the practicability of a public market is the matter of the supply and potential supply of products to be handled in the market. Obviously these two essential factors—demand and supply—must be in proper relationship before a successful market can be created. Open markets have to do primarily with supplies of produce originating within hauling distance. Where little or no good farming land

exists near a city or where the neighboring lands have not been devoted to any great extent to the production of foodstuffs, conditions are unfavorable for the immediate establishment of an open public market of any considerable size. The concentration of available supplies, however, and the admission of hucksters selling shipped-in products will often make possible the creation of a small curb market. Such a market, if intelligently operated, will stimulate additional production by demonstrating that near-by production is remunerative; and the increased production will in turn make a larger market feasible.

A proper location for the market, determined with reference to economic conditions, is essential to its success. Errors of location are probably the most common errors made in establishing public markets. Ease of accessibility to the greatest possible number of producers and consumers is the central consideration in determining location. The essential truth of this principle is evidently not so easily grasped as might be supposed, however, and all too often markets are situated at a given point merely because a certain lot happens to be vacant or because an available site is in a certain ward. A market located in such a haphazard fashion usually demonstrates the importance of location by becoming a hopeless failure.

The importance of market facilities varies in relation to the type of market under consideration as well as in relation to certain local factors. In temperate climates curb markets with practically no special equipment may be entirely satisfactory. In hot regions some sort of protection from the sun becomes desirable, and in most regions protection from rain is necessary. Markets on special market property should be paved and raised curbs against which vehicles may be parked should be provided. On markets of considerable size restrooms and comfort stations are a real necessity. On many public markets appropriate rooms are provided and leased for use as restaurants in order that the patrons of the markets may obtain meals with little loss of time.

In addition to the economic and physical conditions essential to the success of open public markets the matter of management and methods of operation is of great importance. Markets with practically all other conditions for success present are in many cases prevented from realizing more than a partial success because of the unintelligent manner in which they are operated and managed. A market, the existence of which is justified by economic conditions, is capable of being an institution of great importance to the community, and it should be placed in charge of a manager with ability to bring out its full possibilities. The placing of market establishments—often in effect business enterprises representing investments

of hundreds of thousands of dollars—in the hands of poorly paid and incompetent managers can not be too strongly condemned as a short-sighted and wasteful policy.

ESTABLISHMENT OF A MARKET.

When a community, or an organization in a community, desires to establish an open public market, the first step should be the making of a thorough survey to determine whether local conditions are favorable for a market.

A suggestion in topical form of the data that usually are found useful in reaching a determination as to the feasibility of establishing an open public market follows:

Approximate number of each of various types of existing agencies (wholesale and retail) distributing farm produce and their relative importance.

Buying habits of consumers. (Whether food purchases are predominantly on credit or for cash, to what extent delivery is demanded, etc.)

Sentiment of important organizations in regard to the need for a market.

Agricultural conditions in relation to immediate and potential supply of products, in hauling distance of the city, to be sold through the market.

Sentiment among producers in regard to the need for a market.

Grouping of city's population. (Main residence districts, racial districts if marked, etc.)

Location of street railway lines.

Location of main business zone.

Location of most important subordinate business centers.

With the data enumerated available it should be a relatively simple matter to reach an intelligent decision as to whether an open public market should be established; and if so, the type which will best meet local conditions. Unless the existence of both a reasonable supply of local produce and a demand for it is shown, and in addition a desire for a market on the part of a considerable number of consumers and producers, the chances for the success of a market are slight.

If a market seems feasible but only a slight interest is manifested in it or only a small supply of produce is available, the simplest type of curb or vacant lot market only should be established, with a view to the development of a better market or a system of markets later. In relatively small cities, or wherever there is any doubt as to the market being properly supported, it is always safest to begin with a simple type of market, in large measure as a demonstration project. Such beginnings have often led to substantial and healthy

market developments. Practically no financial risk is involved when curb markets are established, and if an error is made in location the market can easily be transferred to another site. When, through the success and growth of a curb market, the existence of proper conditions to assure continued success is demonstrated, investment in permanent market equipment at or very near the site can be made with confidence.

If a survey indicates conclusively that conditions are favorable for an open market of considerable proportions, it may be advisable immediately to establish such a market on a market tract within the property lines. Cities should, however, be literally sure of their ground before making substantial investments for market sites. It will sometimes be possible even where a more permanent type of market is to be opened to lease the ground until the feasibility of a market at that location is tested. If a lease may be obtained with privilege to buy later at a specified figure, thus protecting the municipality from being charged for increases in value which it may itself create through the market, such arrangements should be made.

The products which it is desired to have sold on a market may influence the selection of the type of market; and conversely, the selection of a certain type and kind of market will determine the products which should be handled. If it is desired that fresh meats, milk, and other dairy products, delicatessen preparations, baked goods, and similar foods be sold on the market, an open type should not be selected. Best market practice throughout the country recognizes that open markets on which products are necessarily exposed to a certain extent to sun, wind, and rain, to flying dust, germs, and spores, and to flies and other insects, can not be operated so as to insure the clean handling and sanitation that the foods enumerated demand. In many communities the municipal ordinances relating to public health forbid the exposure of such foods for sale on open markets. In some communities efforts have been made to broaden the scope of open markets by permitting the sale of certain meats and other highly perishable and easily contaminated foods if they are kept in removable screened booths. Such practices only slightly minimize the undesirable features of handling such foods in the open, however, and can not be recommended. Considerations of health and sanitation demand that such foods be sold only in properly equipped shops where conditions of cleanliness can be maintained, and where the establishment of an inclosed market is not economically justified the handling of such foods had better be left to private shops operating under proper sanitary regulations.

If any sort of compromise is necessary in regard to handling meats and similar foods on open markets, it can best be made on a seasonal basis. Thus, in the winter season there may be little objection in

certain parts of the country to the handling of fresh meats and dressed poultry on open markets, especially if sales are confined in the case of meats to pieces of considerable size cut before they are brought to market. If an open market is to be devoted to any considerable extent to the sale of the more perishable farm products, it will be advisable to locate it on special market property, since sanitation can be controlled more satisfactorily under such circumstances than when the market is conducted in a street or along curbs.

Products that may be sold satisfactorily on open markets under ordinary conditions include fresh fruits and vegetables, eggs, live poultry and rabbits, plants, flowers, herbs, canned goods, packaged butter, and cheese. Fruits and vegetables make up the bulk of the products handled on open markets.

In determining the nature of the market to be established the scope in regard to the classes of salesmen permitted on the market should be given consideration. From this point of view open markets are broadly either strictly "producers'" or "farmers' markets," on the one hand, or "producers' and hucksters' markets" on the other. In a very few cases exclusive "hucksters' markets" exist. In some communities it has been felt that complications that might result or evils that might grow from permitting commercial peddlers on the market with producers would more than overbalance any advantages owing to a broadening of the market. This is undoubtedly true if no restrictions are placed on the admission of commercial peddlers, but many communities have found it decidedly advantageous to permit such peddlers or hucksters on the market under proper regulations. The advantage of having hucksters on the market is that they add tropical fruits and other shipped-in products to the otherwise relatively meager assortment which local products alone provide, especially during certain seasons.

The problem of the admission of hucksters often can be satisfactorily solved by permitting them only on a separate section of the market, labeled "Hucksters." As a further restriction only licensed peddlers may be admitted and they may be compelled to exhibit their license tags conspicuously. The matter is sometimes approached from another direction by supplying all bona fide producers with signs reading "Producer." These steps are taken on the theory that consumers have a right to know with what class of vendor they are dealing.

The choice of a site for an open public market should be determined after the type and kind of market to be established have been decided on. In general it may be said that other conditions being favorable a retail market should be placed as near as practicable to the retail shopping district or to important subordinate retail business districts, while a wholesale market should be situated as near as

practicable to the established commercial center for wholesale dealing in fresh produce.

If a curb or street market is to be established a broad well-paved street should be chosen, if properly located. A market tract should be practically level but well drained. If the tract can not be paved immediately soils which form mud readily should be avoided. Considerations of topography and soil, however, can be remedied without great difficulty and should be given much less weight than the economic considerations determining location.

FIG. 1.—Simple retail market without structures in small town. Produce is sold from wagons and from baskets and sacks on the curb.

Many street and curb markets are practically without equipment, sales being made from wagons or from baskets and other containers set on the edges of sidewalks. (See fig. 1.) On some curb markets the municipality furnishes small movable booths or tables which are set up on the walks on market days, while on other markets such equipment is furnished by the producers and other vendors and is removed by them when the markets are closed.

On a number of curb markets especially in the South and Southwest, removable frames and awnings or large umbrellas are used to protect the sellers and their wares. In at least one case, in a large western city, permanent steel sheds have been constructed along the portion of a business street devoted to a curb market.

Where it is possible in locating a curb market to select a satisfactory site, insofar as other considerations are concerned, on one of several types of pavement, a smooth hard type such as concrete should be chosen in preference to cobblestone. It is difficult even with repeated flushings to keep rough cobble surface in a sanitary condition. Asphalt pavements are also preferable to cobblestone in the cooler sections of the United States, but in the warmer sections such pavements soften and may be seriously injured by stamping horses. Where only temporary or inexpensive improvements are to be made on special market sites a gravel or cinder surface often will give fair satisfaction.

The kinds of structures used for shelter on open public markets in the United States vary from simple sheds, barely wide enough to

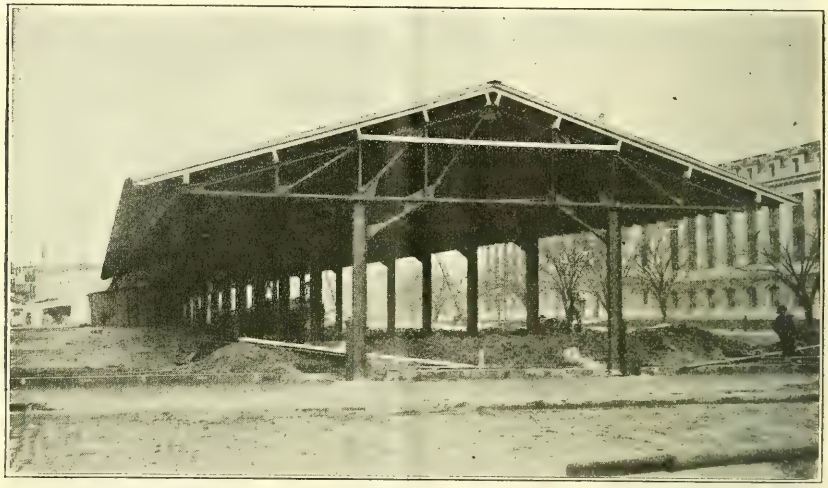

FIG. 2.—End view of good type of double overhanging market shed showing steel construction. This shed is used on a wholesale market but is better suited to a retail market.

cover a single wagon, to broad structures roofing the entire market tract. Very narrow sheds are seldom satisfactory. One of the most popular types of shed is centered over a walk with curbs 8 to 12 inches high the shed having sufficient overhang to protect vehicles on both sides of the walk, backed against the curbs. Such a type of shed, built from structural steel, is shown in figures 2 and 3. Sheds of this type may also be constructed of timber or concrete.

The type of structure which may be used in units to cover completely the market tract is shown in figure 4. Of course, such structures are more costly than the simpler types of sheds. The wider sheds are not needed on open retail markets except perhaps those in large cities, but may be very useful for wholesale markets especially where such markets do an important business throughout the year.

The investment of the relatively large amounts of money needed to erect such structures would hardly seem to be justified except on markets already well established and giving promise of a thriving future. Where open retail markets of considerable size have thoroughly demonstrated their stability and importance and especially where the market's activities are important even during the winter season, it may be worth while even to build a shelter that makes possible when desired the temporary conversion of the open market into an inclosed market. Such a structure may be a shed of any one of the several designs illustrated having an overhang sufficient to cover entirely vehicles and teams, and provided with doors which are easily removable.

FIG. 3.—Market plot developed by a series of parallel shed units. Some of these units are used for wholesale transactions, some for retail trade.

Proper financing is essential to the full success of a market, whether it be under the ownership of a municipality, an association, or a corporation.

In most cases in which markets have failed or are of slight value, poor methods of financing are found to be contributing factors. The most common error in the case of municipal markets is to turn all receipts into the general treasury of the city and to pay all expenses by special appropriations, thus obscuring the relationship between income and outgo. Best practice among successful markets seems to favor the creation of a market fund into which are deposited all market receipts and from which are paid all market expenses. Fees should be fixed so that they conform as nearly as practicable to the relative values of the different spaces and so that the aggregate income will be sufficient to pay all expenses, including depreciation and

interest on investment. It is often possible to obtain for market spaces rentals high enough to create a considerable surplus over expenses, but municipalities should not yield to the temptation to utilize their markets as producers of surplus revenue. Obviously the charging of higher rentals adds to the expense of operation by those doing business in the markets and makes it more difficult for the markets to fulfill their primary function—that is, to reduce the expense of food distribution and so to make possible the charging of relatively low prices for the products handled.

In establishing a new market it is important that preliminary work be done by the agencies interested in making it a success in order that the interest of both producers and consumers be awakened. If

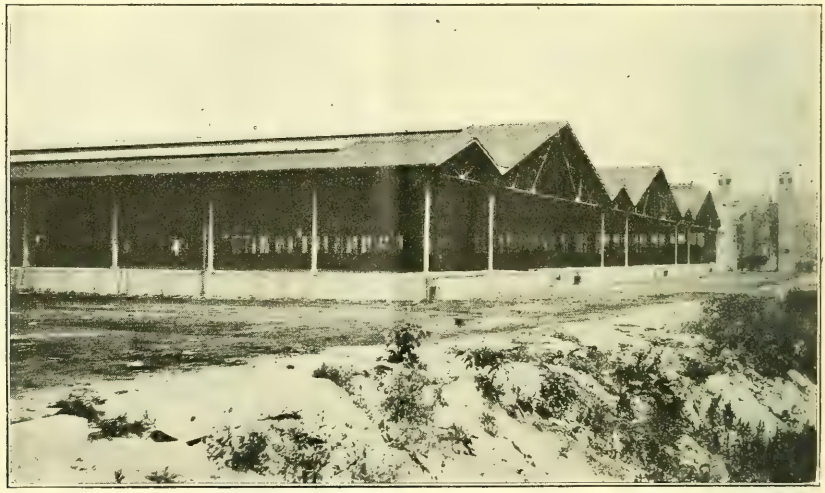

FIG. 4.—Wholesale market completely covered by sheds. The wider roof sections cover spaces for trucks and wagons and teams; the narrower sections cover platforms for unloading.

such work is neglected there is strong likelihood that there will be a lack of proper balance between supply and demand. If producers bring their wares on the opening day and find an insufficient number of consumers to absorb the supply they are likely to become discouraged and to spread pessimistic reports of the new enterprise to other producers. Similarly, if a large number of consumers attend the opening of the market and find a meager supply of produce, conditions will again be unfavorable for the rapid development of the new enterprise. In carrying on campaigns to popularize proposed markets it has been found that personal work, such as visits to leading farmers and the making of talks to associations of producers in the country, is of much greater value than circularization or other indirect methods. Among consumers it will be found valuable to interest

women's clubs, labor organizations, and similar agencies. The cooperation of the press should also be obtained. The economics of the market enterprise should be frankly discussed with grocers' organizations, chambers of commerce, and boards of trade in an effort to show that the establishment of the market will be beneficial to all classes of the community.

If the market is to be established under municipal auspices, it will be necessary that an appropriate ordinance be adopted unless one exists on the statute books. The agencies seeking to bring about the establishment of a market should obtain adequate legal assistance in the drafting of an ordinance to meet local conditions and needs.[1]

If the market is to be under private operation it will probably be necessary or desirable to form a corporation. Competent legal advice should be obtained.

OPERATION OF A MARKET.

The importance of intelligent management of a market has been indicated. The mistake should not be made of obtaining the services of a mere caretaker. The success or failure of a market will depend as much on whether an efficient or an inefficient manager is placed in charge as on any other factor. An effort should be made to employ as manager a man familiar with the merchandising of food products, who understands and is in sympathy with the functions of a public market, and who can be depended upon to do all in his power to make the enterprise a success.

A certain amount of bookkeeping will be necessary even on the smallest market of the simplest type. A system of tickets, receipts, and stubs can be devised, however, which will greatly simplify such work. The names and addresses of producers who rent reserved space, together with the numbers of their stalls, should be kept on file in the manager's office.

On some of the larger municipal markets a staff of assistants has been developed under the supervision of the market management through which is collected each day information in regard to prevailing prices and quantities of the several products on the market and other market data. This information is incorporated into a daily bulletin which is mailed for a small subscripton price to farmers, dealers, and other interested parties. It is also made available to the local press.

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[1] A full suggestive ordinance from which provisions may be selected to meet the needs of most municipalities has been published by the United States Department of Agriculture as Service and Regulatory Announcement (Markets) 69. A copy will be sent on application to the Bureau of Markets and Crop Estimates, Washington, D. C.

SUMMARY.

Public markets are not agencies to replace other means of distribution of farm produce. They are supplementary agencies to aid, under favorable conditions, in efficient distribution. It should not be assumed that such markets will be successful under all conditions and in all localities. Definite economic conditions must exist in a community before it is advisable to establish a public market there. Before steps are taken actually to establish a public market in a community there should be a careful stock taking of local conditions to determine whether the opening of a market is advisable, and if so, in what form the institution should be cast so as best to meet local needs. In the case of a municipally owned market an ordinance should be carefully drawn embodying the conclusions that have been reached. Such an ordinance should be as simple as the conditions to be met will permit. The final and one of the crucial factors in determining the degree of success of a market is management. The general administration of the enterprise should be placed in the hands of a city department or a special board selected because of its fitness to cope with the problems which a market faces. Above all things, the direct operation of the market should be entrusted to a capable and experienced manager.

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THE DISTILLATION OF STUMPWOOD AND LOGGING WASTE OF WESTERN YELLOW PINE.

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IMPORTANCE OF WESTERN YELLOW PINE.

Western yellow pine (*Pinus ponderosa*) is the most widely distributed of the western commercial softwoods (4, 10)[2] (fig. 1). The Forest Service estimates the amount of standing timber of this species to be approximately 335,000,000,000 board feet, or more than that of any other species except Douglas fir (6). The reported cut for this species for 1917 was 1,862,914,815 board feet. This represents an area of more than 350,000 acres of land annually cleared and left covered with stumps after logging operations. About one-third of this is within the national forests and is generally of little value for agriculture, because of the roughness of the land. Much of the remaining two-thirds, however, is valuable for crops.

[1] The sections on the importance and distribution of the western yellow pine are by C. H. Shattuck. The report of the investigation is by M. G. Donk.

[2] The numbers in parenthesis throughout this bulletin refer to the bibliography on page 69.

Removing the stumps is arduous and costly (8), and so far they have been considered to be worthless after removal. Any process which may serve to reduce the cost of clearing the land or lead to the discovery of a profitable use for the stumps is, therefore, worthy of careful consideration. Observations on the methods of utilizing the more resinous portions of the yellow pine of the South in the manufacture of wood-distillation products suggested the possibility that the western species might serve the same purpose, as these trees, especially the stumps, are often quite resinous.

It is well known that western yellow pine was used in California as a profitable source of turpentine during the Civil War (13). In speaking of turpentine obtained from western yellow pine, Schorger (7) says: "There is no reason to suppose that both the California and the Arizona oils will not serve the purposes for which ordinary turpentine is commonly used." According to Betts (2), nearly as much turpentine and rosin was obtained from western yellow pine as from the pines of the Southeast. Wenzell (5) states that the odor, specific gravity, and boiling point of oleoresin from *Pinus ponderosa* correspond with those of the common oil of turpentine. It is therefore reasonable to suppose that turpentine operations in the large tracts of virgin pine timber in the West will be undertaken within a few years, because of the rapid cutting of the yellow pine of the South.

DISTRIBUTION OF WESTERN YELLOW PINE.

For convenience the chief areas of western yellow pine may be grouped as follows:

(1) Arizona and New Mexico.
(2) California.
(3) Oregon and Washington.
(4) Idaho, Montana, and Utah.
(5) Colorado, South Dakota, and Wyoming.

For want of accurate data, no estimates covering the quantities of this species annually cut for fuel and uses other than for lumber are given, although this amount is known to be considerable. Neither is any account taken of the distillation material to be derived from "fat" limbs and "pitchy" butts.

The estimates of stands, and therefore of stumps, in many of the States are low because the results of the cruises of much privately owned timber were not obtainable.

The problem of the better utilization of this species is by no means confined to Idaho. Tables 2 to 12 and the map (fig. 1) furnish conclusive proof of the enormous quantities of yellow-pine stumps to be had in several Western States. It will not be profitable to work up by distillation methods any but the more resinous of the stumps, "fat" limbs, and "pitchy" butts. A complete field survey of each

region to determine the stand or number of rich resinous stumps and the practicability of profitable distillation must be left to those in

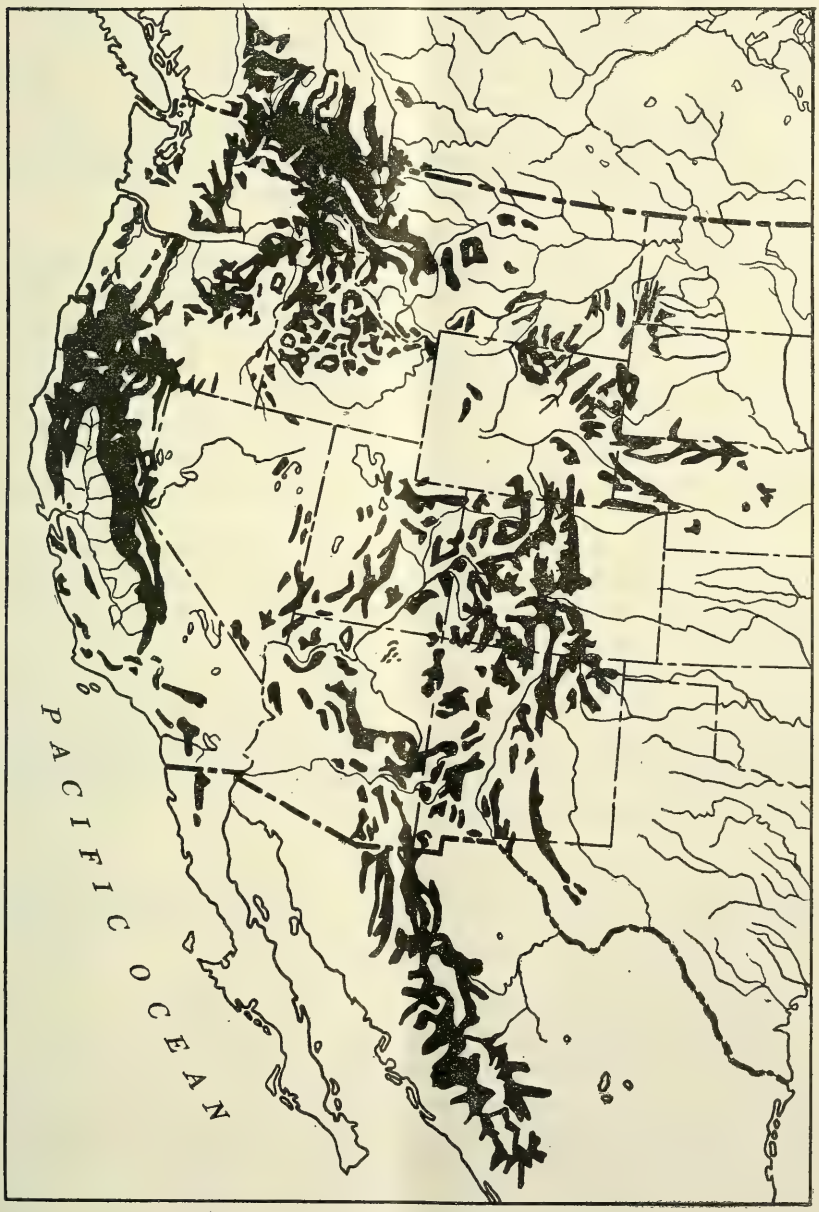

FIG. 1.—Geographic distribution of *Pinus ponderosa*.

the various regions who plan to enter the field of wood-distillation from a commercial standpoint. Such a survey, however, should always be made before undertaking distillation in any section.

ARIZONA AND NEW MEXICO.

Total area in the national forests	acres	[3] 4,571,425
Total stand in the national forests	board feet	17,002,000,000
Total annual cut (1917)	do	154,297,815
Total area annually cleared (if clear cutting is employed)	acres	38,574
Total annual volume of stumpwood	cords	[4] 77,148

For average stands the number of trees over 18 inches varies from 85 to 12, and the number of those over 24 inches varies from 7 to 9; heavy stands have from 12 to 30 trees 18 inches and over, and from 11.5 to 20 trees 24 inches and over.

Since 500 board feet is a liberal average volume for a yellow-pine tree 22 inches in diameter at breast height, or 24 inches on the stump (3, 13), stands of 5,000 feet an acre would contain 10 trees averaging 24 inches on the stump. The average stand over Arizona and New Mexico being approximately 4,000 board feet for all the area covered with yellow pine, the average number of 24-inch stumps an acre would be 8. Many thousands of acres show stands above 5,000 feet, the actual number of trees 24 inches and over being from 10 to 15 to the acre.

It is evident, therefore, that this region has future possibilities from the standpoint of wood by-products, if it is found that a fair percentage of the stumps are rich in resin. No account has been taken of the material obtainable from "fat" limbs or "pitchy" butts, and only the timber on national forests, where accurate cruises have been made, is here considered. Though no figures are available for the timber on private holdings, Indian lands, and the public domain, it is known that these areas are quite extensive, and many of the stands are average or better.

CALIFORNIA.

Total area	acres	10,000,000
Total stand	board feet	85,000,000,000
Total annual cut (1917)	do	154,297,815
Total area annually cleared (if clear cutting is employed)	acres	38,574
Total annual volume of stumpwood	cords	[4] 77,148

California has about 10,500,000 acres of commercial yellow pine, with from 85,000,000,000 to 90,000,000,000 board feet, or from 8,000 to 12,000 board feet an acre. Trees above 12 inches in diameter, breast high, have an average diameter of 38 inches, or approximately 41 inches on the stump, for which reason the yellow-pine trees of California are the largest known. Since the species usually grows in mixed stands, the number of trees an acre is low. The pitch content, however, is higher than that in any other section. As the yellow pine in California is the heaviest known (Table 1), the amount of "pitchy" wood can safely be taken as average or better.

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[3] National forests only.

[4] For reducing factors see Table 6.

TABLE 1.—*Stands of western yellow pine in California, Oregon, and Washington, with reduction factors for various volumes and diameters of trees and stumps.*[1]

Diameter.			Average volume—		
Breast high.	Reduction, breast height to stump height.	Stump high.[2]	Of trees.	Of stumps.	Reduction units for different volumes and diameters.
Inches.	*Inches.*	*Inches.*	*Bd. ft.*	*Cords.*	
22	2	24	500	0.25	1
23	2	25	600	.....	.....
24	2	26	750	.375	1.5
25	2	27	850	.....	.....
26	2	28	950	.....	.....
26.5	2	28.5	1,000	.5	2
27	2	29	1,150	.....	.....
28	2.5	30.5	1,250	.625	2.5
29	2.5	31.5	1,350	.....	.....
30	2.5	32.5	1,425	.....	.....
30.5	2.5	33	1,500	.75	3
32	2.5	34.5	1,600	.....	.....
32.5	2.5	35	1,750	.....	3.5
33	2.5	35.5	1,850	.875	.....
33.5	2.5	36	1,925	.....	.....
34	3	37	2,000	1	4
35	3	38	2,150	.....	.....
36	3	39	2,250	1.125	4.5
37	3	40	2,400	.....	.....
38	3	41	2,500	1.25	5
39	3.5	42.5	2,600	.....	.....
40	3.5	43.5	2,750	1.375	5.5
41	3.5	44.5	3,000	1.5	6
41.5	3.5	45	3,250	1.625	6.5
42	3.5	45.5	3,500	1.75	7
43	3.5	46.5	3,750	1.875	7.5
44	3.5	47.5	3,900	.....	.....
45	4	49	4,000	2	8

[1] This working table must be adapted by the user to meet the variations from the normal stand as they are found to occur. The volumes in board feet represent close approximations of the averages of all obtainable volume tables for the regions named. The volumes in cords are taken from measurements of corded stumpwood in various regions, and are as conservative, when the wood is split for the retort, as those used for volume, B. M.

[2] The height of the stump is here assumed to be 18 inches. For higher stumps the diameter would be duced according to the scale, as given in columns 5 and 6.

TABLE 2.—*Sample cruises of California yellow pine from different parts of the State, with volume and acre equivalent in number of stumps of various diameters required to produce the given yields (area covered, 6,400 acres, average stand, or slightly better).*[1]

Location.	Volume per acre.	Number stumps.			Per cent total stand.
		24-inch.	28.5-inch.	37-inch.	
	Bd. ft.				
Eldorado, T 8 N, R 15 E, sec. 35	10,082	20.00	10.00	5.00	83.6
Lassen, T 25 N, R 14 E, sec. 24	10,501	21.00	10.50	5.25	64.7
Lassen, T 27 N, R 10 E, sec. 5	18,236	36.40	18.20	9.10	46.4
Lassen, T 32 N, R 8 E, sec. —	12,253	24.50	12.25	6.12	68.5
Modoc, T 46 N, R 15 E, sec. 32	12,444	24.88	12.44	6.22	87.6
Plumas, T 23 N, R 9 E, sec. 5	9,503	19.00	9.50	4.80	26.9
Sequoia, T 13 S, R 19 E, sec. 19	5,870	11.74	5 87	3.92	71.6
Sierra, T 5 S, R 21 E, sec. 18	10,518	21.02	10.51	5.25	83.4
Sierra, T 6 S, R 24 E, sec. 27	17,163	34.32	17.16	8.58	72.1
Stanislaus, T 4 N R 18 E, sec. 17	12,276	24.55	12.27	6.11	47.4
Average for 6,400 acres	11,884	23.75	11.88	5.94	64.5

[1] Estimates furnished by T. D. Woodbury, assistant district forester, San Francisco, Calif. If the stump-high diameters were used instead of those breast high, a large number of trees would be included in the 24-inch class, as many trees measuring 22 inches and over, breast high, would come within the 24-inch class if measured on the stump.

TABLE 3.—*Practical application of Table 1.*

Location.	Area.	Volume per acre.	Trees 24 inches and over.	Average diameter stump high.	Stumps per acre equivalent.				
					24-inch.	33-inch.	35-inch.	43-inch.	49-inch.
	Acres.	*Bd. ft.*		*Inches.*					
T 4 N, R 18 E, sec. 19	7	35,490	9.1	48.0	70.9	23.6	20.3	12.8	8.8
T 9 S, R 24 E, sec. 2	16	10,700	6.6	34.5	21.4	7.1	6.1	.....	.....
T 9 N, R 24 E, sec. 1	16	9,746	5.5	32.0	19.5	6.5	.....	.....	.....
T 8 N, R 23 E, sec. 15	16	11,000	4.0	43.5	22.0	7.3	.....	4.0	.....
T 4 N, R 21 E, sec. 32	16	13,112	4.7	43.5	26.2	8.7	.....	4.7	.....
T 10 and 11 S, R 25 and 36 E	17,495	12,200	.....	33.0	24.4	8.1	.....	.....	.....
T 4 and 5 S, R 20 and 21 E	6,393	6,710	.....	32.5	13 4	4.5	.....	.....	.....
T 3 and 4 S, R 19 E	3,820	6,770	.....	33.5	13.5	4.5	.....	.....	.....
T 7 S, R 22 E	300	8,139	.....	33.0	16.2	5.4	.....	.....	.....
Volume equivalents:									
Lumber (board feet)	.....	500	1,000	1,500	2,000	2,500	3,000	3,500	4,000
Stumpwood (cord)	.....	.25	.50	.75	1.0	1.25	1.50	1.75	2.00

OREGON AND WASHINGTON.

	Oregon.	Washington.
Total area ... acres	10,000,000	3,400,000
Total stand ... board feet	70,000,000,000	17,000,000,000
Volume per acre ... do	7,000	5,000
Total annual cut (1917) ... do	470,488,000	220,924,000
Total area annually cleared (1917) ... acres	67,212	44,185
Total annual volume of stumpwood ... cords	235,244	110,462

Western yellow pine occurs on about 14,000,000 acres in Oregon, practically a quarter of the State and half of its timbered land. Of this area about 10,000,000 acres may be classed as commercial forest, the estimated stand amounting to 70,000,000,000 board feet, or an average of 7,000 board feet an acre, interforest waste areas included (6).

TABLE 4.—*Representative western yellow-pine stands in Oregon.*

Location.	Area.	Average number of trees.			Per cent of stand.
		12-inch and over.	18-inch and over.	24-inch and over.	
	Acres.				
Near Austin and Whitney	258	25.42	18.97	13.78	83.2
Near Lookingglass Creek	44	34.57	21.34	15.48	87.3
Near Embody	30	32.00	21.23	15.10	99.5
Klamath Lake Section	159	25.37	19.85	15.41	75.2

Table 4 shows average stands of Oregon yellow pine more or less mixed with other timber. Pure stands contain a proportionately greater number of trees. In cruises made by the United States Geological Survey, on pure, heavy stands of yellow pine near Richland, the average number of trees above 12 inches on strip acres ran from 30 to 43, and of those above 22 inches, from 15 to 24. The timber on these strips, running about 10,000 feet an acre, will yield approximately 5 cords of stumpwood an acre.

Munger (6) states that 42 per cent of all butt logs in Oregon are fire scarred, and that 25 per cent of them are "pitched." The average diameter of the "pitchy" area on the basal cross section of the log is 14.7 inches on a tally of 1,184 butt logs. This means that 25 per cent of the stumps would also be "pitched" as the result of fire alone (p. 8).

TABLE 5.—*Cruises on the Whitman National Forest, 1912–1916.*

Location.	Area.	Total volume.	Volume per acre.	Number of stumps per acre.				Volume.	
				24-inch.	28.5-inch.	33.5-inch.	37-inch.	Per acre.	Per area.
	Acres.	*Bd. ft.*	*Bd. ft.*					*Cords.*	*Cords.*
T 10S, R 34E, sec. 19	640	8,511,000	13,299	26.59	13.29	8.86	6.649	6.649	4,255
T 10S, R 34E, sec. 33	640	6,220,000	9,718	19.43	9.72	6.48	4.859	4.859	3,109
T 10S, R 34E, sec. 34	640	7,440,000	11,006	22.00	11.00	7.34	5.503	5.503	3,521
T 11S, R 34E, sec. 1	640	5,128,000	8,012	16.02	8.01	5.34	4.006	4.006	2,564
T 11S, R 34E, sec. 2	640	5,716,000	8,931	17.86	8.93	5.95	4.465	4.465	2,857
T 11S, R 34E, sec. 11	640	6,992,000	10,925	21.85	10.92	7.28	5.462	5.462	3,495
T 11S, R 23E, sec. 23	640	6,260,000	9,781	19.56	9.78	6.52	4.890	4.890	3,130
T 12S, R 34E, sec. 3	640	5,900,000	9,287	18.57	9.28	6.19	4.643	4.643	2,971
T 12S, R 34E, sec. 10	640	4,776,000	7,448	14.89	7.44	4.96	3.724	3.724	2,383
T 12S, R 34E, sec. 21	640	3,153,000	4,926	9.85	4.92	3.28	2.463	2.463	1,576
T 12S, R 34E, sec. 28	640	8,110,000	12,672	25.36	12.68	8.45	6.336	6.336	4,056
Total	7,040	67,701,000							33,916
Average			9,474	18.95	9.47	6.32	4.737	4.737	
Stand on 56 forties	2,240	30,821,000	13,759	27.52	13.76	9.17	6.879	6.879	15,409
Stand on 27 sections	17,280	153,565,000	8,886	17.77	8.88	5.92	4.443	4.443	76,775

The total stand of western yellow pine for Washington is 12,500,000,000 feet in private and State ownership, and 4,500,000,000 feet in Government ownership, or a total of 17,000,000,000 board feet. Allowing a stand of 5,000 feet an acre, which is thought to be low, since Oregon and Washington are similar, the Washington area will be approximately 3,400,000 acres.

The area of the yellow-pine land in the two States is approximately 13,400,000 acres, carrying a commercial stand of from 5,000 to 7,000 feet an acre, or the equivalent of from 10 to 14 trees 24 inches on the stump, which will yield from $2\frac{1}{2}$ to $6\frac{3}{4}$ cords of yellow-pine stumpwood an acre.

IDAHO, MONTANA, AND UTAH.

	Idaho.	Montana.	Utah.
Total area ... acres	10,000,000	3,500,000	(1)
Total stand ... board feet	58,050,000,000	14,000,000,000	(1)
Volume per acre ... do	5,800	4,000	4,000
Total annual cut (1917) ... do	315,009,000	150,905,000	4,676,000
Total area annually cleared (1917) ... acres	54,311	37,726	1,169
Total annual volume of stumpwood ... cords	157,504	75,452	2,338

[1] No reliable figures obtainable.

Many large areas of yellow-pine timber in Idaho are as good as the best of that in California and Oregon, but as a whole the stand

will probably average close to 6,000 feet an acre. Conservative estimates for the area would be 10,000,000 acres, and for the total stand, 50,000,000,000 feet.

There is much wastage in butt logs, due to "pitchiness" resulting from fire scars and natural causes. Fires tend to make the stumps more resinous and to increase the number of those sufficiently "fat" to serve for purposes of distillation. It has been the experience of an Idaho lumber company that some of these "pitchy" butts occur in all the western yellow-pine timber. They state that these pitchy butts are more prevalent in the northern section of Idaho, but that this territory and the Baker, Oregon (Blue Mountain), territory pro-

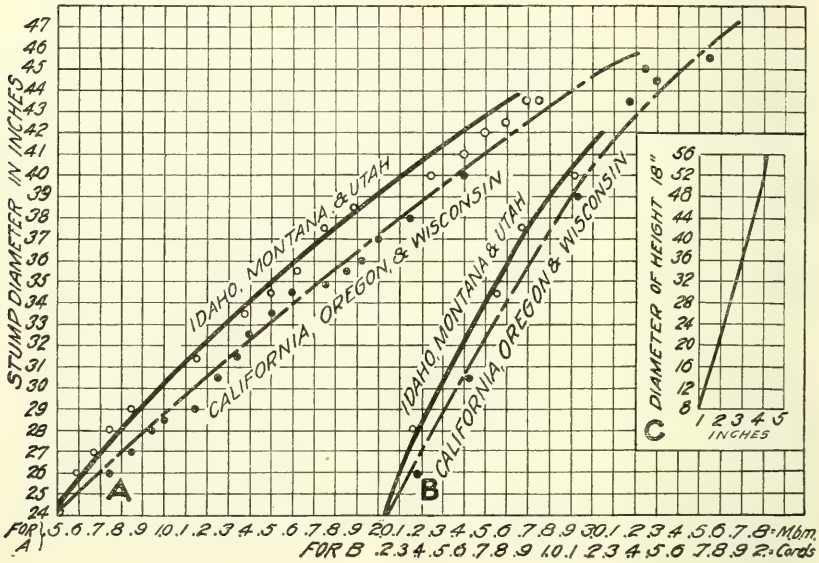

FIG. 2.—Yellow-pine stumpage in 6 western States. A, volume of tree (thousand board feet); B, volume of stumpage (cords); C, difference between diameter breast high and diameter stump high (inches).

duce less "pitchy" lumber than any other yellow-pine section that has come under their observation.

From this it would seem that the question of "pitchy" butts is important, and should not be ignored by those who attempt to determine the amount of resinous wood to be obtained from any locality. Since 25 per cent of the butt logs from the Blue Mountain region bear more or less pitch, and a wastage in "pitchy" butts trimmed off of from 4 to 5 cords a day is reported by one company, this constitutes a very important source of valuable wood for distillation purposes. Samples sent to the University of Idaho compared favorably with the best stumpwood in yield of products. The

mill which submitted the samples was compelled to sell more than a million board feet of yellow-pine lumber at a loss, because of the amount of "pitchy" lumber in the butt logs. Inspection by one of the writers showed a large amount of this wood to be suitable for distillation.

TABLE 6.—*Average volume of western yellow pine and reduction factors for various volumes and diameters of trees and stumps (Idaho and Montana).*

Diameter.			Average volume.		Reduction unit for different volumes and diameters.
Breast high.	Reduction, breast height to stump height.	Stump high.[1]	Of tree.	Of stump.	
Inches.	*Inches.*	*Inches.*	*Bd. ft.*	*Cords.*	
22	2.0	24.0	500	0.25	1.0
23	2.0	25.0	550	.....	.....
24	2.0	26.0	600	.....	.....
25	2.0	27.0	675	.....	.....
26	2.0	28.0	750	0.375	1.5
27	2.0	29.0	850	.....	.....
28	2.0	30.0	1,000	0.50	2.0
29	2.5	31.5	1,150	.....	.....
30	2.5	32.5	1,250	0.625	2.5
31	2.5	33.5	1,375	.....	.....
32	2.5	34.5	1,500	0.75	3.0
33	2.5	35.5	1,625	.....	.....
34	3.0	37.5	1,750	0.875	3.5
35	3.0	38.5	1,875	.....	.....
36	3.0	39.0	2,000	1.00	4.0
37	3.0	40.0	2,250	1.125	4.5
38	3.0	41.0	2,400	.....	.....
38.5	3.5	42.0	2,500	1.25	5.0
39	3.5	42.5	2,600	.....	.....
40	3.5	43.5	2,700	.....	.....
40.5	3.5	44.0	2,850	.....	.....
42	3.5	45.5	3,000	1.50	6.0

[1] See also Figure 2.

TABLE 7.—*Cruise of 160 acres of western yellow pine in Boise County, Idaho (all trees calipered).*

Location.	Average stand per acre.	Average diameter.		Number 24-inch stumps per acre equivalent.	Number stumps per acre equivalent, based on average diameter.	Stumpwood.		Equivalent used in reduction.
		Breast high.	Stump high.[1]			Per acre.	Per section.	
	Bd. ft.	*Inches.*	*Inches.*			*Cords.*	*Cords.*	*Bd. ft.*
T 6N, R 5E, sec. 8 NW NW	14,693	25.5	27.5	29.38	20.55	7.34	293.6	715
T 7N, R 4E, sec. 35 SE NE	15,144	27.4	29.4	30.29	16.83	7.57	302.8	900
T 7N, R 4E, sec. 35 NE NE	13,866	25.5	27.5	27.73	19.40	6.93	277.2	715
T 7N, R 4E, sec. 35 NE SE	15,783	26.7	28.7	31.57	18.70	7.89	315.6	800
Average, 4 forties	14,896	26.27	28.27	29.74	19.12	7.681	[2] 189.2	782.5

[1] From Table 6.
[2] Total number of cords of stumpwood for entire area.

TABLE 8.—*Cruises of 478.85 acres of western yellow pine in Latah County, Idaho.*

Location.	Average stand per acre.	Average diameter.		Number 24-inch stumps per acre equivalent.	Number stumps per acre equivalent, based on average diameter.	Stumpwood.		Equivalent used in reduction.
		Breast high.	Stump high.[1]			Per acre.	Per area.	
	Bd. ft.	*Inches.*	*Inches.*			*Cords.*	*Cords.*	*Bd. ft.*
T 39N, R 1W, sec. 2, lot 7	8,750	29	31.5	17.50	7.60	4.18	162.39	1,150
T 39N, R 1W, sec. 9 SE NW	10,625	34	37.5	21.25	6.07	5.12	204.80	1,750
T 39N, R 1W, sec. 23 NE SW	8,750	34	37.5	17.50	5.00	4.19	167.60	1,750
T 40N, R 1W, sec. 23 NE SW	7,500	28	30.0	13.00	7.50	3.75	150.00	1,000
T 40N, R 1W, sec. 24 NE NE	10,500	26	28.0	21.00	14.00	5.25	210.00	750
T 40N, R 1W, sec. 24 NE SE	8,925	26	28.0	17.86	11.89	4.46	178.40	750
T 40N, R 2W, sec. 14 SE NW	11,875	26	28.0	23.75	15.83	5.93	237.20	750
T 42N, R 3W, sec. 36 NE NW	17,500	29	31.5	35.00	15.30	8.75	350.00	1,150
T 41N, R 4W, sec. 29 SE SE	9,625	34	37.5	19.25	5.50	4.81	192.40	1,750
T 41N, R 4W, sec. 31 SE NW	10,000	32	34.5	20.00	6.67	5.00	200.00	1,500
T 42N, R 4W, sec. 33 SE NW	11,500	30	32.5	23.00	9.20	5.57	222.80	1,250
T 42N, R 5W, sec. 36 SW SE	11,000	29.5	32.0	22.00	9.17	5.50	220.00	1,200
Average, per forty	10,545	29.8	32.38	21.09	9.48	5.21	207.97	1,229

[1] From Table 6.

TABLE 9.—*Recapitulation of cruises.*[1]

Location.	Area cruised.	Total stand.	Volume per acre.	Number 24-inch trees per acre equivalent.	Stumpwood.	
					Per acre.	Per area.
	Acres.	*Bd. ft.*	*Bd. ft.*		*Cords.*	*Cords.*
T 39N, R 1W, B M	4,840	24,967,000	5,158	10.32	2.57	12,438
T 40N, R 1W, B M	10,291	52,218,000	5,074	10.15	2.53	26,136
T 40N, R 2W, B M	7,380	69,125,000	9,366	18.73	4.68	34,538
T 42N, R 3W, B M	4,733	36,894,000	7,729	15.46	3.86	18,423
T 41N, R 4W, B M	6,147	37,525,000	6,098	12.21	3.04	18,686
T 42N, R 4W, B M	4,240	25,680,000	6,056	12.06	3.02	12,804
Total	37,671	246,409,000				123,025
Average			6,580	13.15	3.28	

[1] The estimates include only yellow pine, which constituted but 53.34 per cent of the entire stand. A pure stand would be heavier.

In all tables a slight discrepancy will be noticed between the total number of cords of stumpwood, when added and when computed. This is due to the dropping of decimals and the using of even numbers only in cruise tables.

The average stand over large areas of yellow pine in Idaho is from 5,000 to 15,000 board feet an acre, or from 10 to 30 trees, 24 inches in diameter on the stump, the volume of stumpwood running from 2½ to 8 cords an acre. For more open stands the number of stumps will be less, but such stumps are generally larger and consequently more resinous. Therefore the volume of "pitchy" wood will be considerable, but can be determined only by a field survey of each region.

TABLE 10.—*Cruises of 3,200 acres of western yellow pine in Boise County, Idaho.*[1]

Location.	Average per acre for section.	Average diameter.		No. 24-inch stumps per acre equivalent.	No. stumps per acre equivalent, based on average diameter.	Stumpwood.		Diameter equivalent, used in reduction.
		Breast high.	Stump high.			Per acre.	Per section.	
	Bd. ft.	*Inches.*	*Inches.*			*Cords.*	*Cords.*	*Bd. ft.*
T 7 N, R 5 E, sec. 12	9,945	29.2	31.7	19.90	8.50	4.97	3,180.8	1,170
T 7 N, R 4 E, sec. 35	10,960	25.5	27.5	21.92	15.10	5.19	3,321.6	715
T 14 N, R 5 E, sec. 30	15,336	28.5	30.5	30.66	14.60	7.66	4,902.4	1,050
T 14 N, R 3 E, sec. 12	18,814	31.0	35.5	37.63	13.68	9.40	6,016.0	1,375
T 13 N, R 5 E, sec. 7	10,453	22.3	25.3	20.90	18.66	5.22	3,340.8	560
Average	13,101	27.3	29.7	26.20	14.11	6.51	[2]20,761.2	974

[1] Only yellow pine which is practically all over 22 inches diameter, breast high, or 24 inches diameter, stump high, is included.
[2] Total number of cords of stumpwood for the entire area.

TABLE 11.—*Recapitulation of cruises of 509,670 acres of pure western yellow pine.*

Location.	Area.	Diameter, stump high.	No. trees.		Average diameter, stump high.	Average No. bd. ft. per tree.	No. bd. ft. per acre.	Average no. 24-inch stumps per acre equivalent.	No. stumps per acre of average diameter.	Average no. cords stumpwood per acre.
			Total.	Average per acre.						
Kaibab National Forest	*Acres.* 300,000	*Inches.* 13–16	3,258,000	11.76	*Inches.* 15.00	145	1,705			
		18–22	2,400,000	8.00	20.18	330	2,600			
		24+	2,220,000	6.74	28.70	820	5,527	11.05	6.74	4.0
Total			8,148,000	25.50			9,838			
South Payette River, Payette National Forest	52,440	13–16	298,908	5.7	14.8	140	798			
		18–22	167,808	3.2	21.1	410	1,312			
		24+	403,788	7.7	28.2	770	5,929	11.86	7.50	3.62
Total			870,504	16.6			8,039			
Middle Fork, Payette National Forest	58,690	13–16	297,558	5.07	15.38	155	786			
		18–22	190,742	3.25	20.50	355	1,154			
		24+	434,306	7.40	29.50	900	6,660	13.32	7.40	3.9
Total			922,606	15.72			8,600			
Weiser National Forest	98,540	13–16	451,367	4.68	14.29	120	562			
		18–22	274,926	2.79	20.04	325	907			
		24+	675,984	6.86	29.00	850	5,831	11.66	6.86	3.36
Total			1,402,277	14.33			7,300			

All commercial stands of yellow pine in Montana are confined to the western part of the State. Much of the timber is of about the same grade as that found in Idaho, but the stand usually is lighter and the timber a little shorter, and as a rule it contains a slightly smaller percentage of "pitchy" stumps. Many large areas in the

State carry heavy stands of from 5,000 to 7,000 board feet, and in time the resinous wood may be handled to commercial advantage. The working tables for Idaho can readily be applied in efforts to determine the volume of stumpwood on any area. The average stand to the acre for the entire commercial yellow-pine region of the State may be taken to be 4,000 board feet.

The yellow-pine region of Utah is scattered over an extensive area, and until a more detailed survey is made it will be impossible to state the value of the stumpwood for distillation purposes. As a rule, it is far from transportation facilities and markets, so that for the present it may be considered as having but a slight bearing on the distillation problem. It has been assumed that the average stand from which the 1917 lumber cut was obtained carried 3,000 board feet an acre. In all probability it was decidedly higher, as the best stands are generally being cut first. This would reduce the number of acres annually cleared, but would not affect the volume of stumpwood.

COLORADO, SOUTH DAKOTA, AND WYOMING.

	Colorado.	South Dakota.	Wyoming.
Total area [1] ..... acres	916,415	707,000	8,000
Total stand [1] ..... board feet	1,618,614,000	2,873,000,000	23,500,000
Volume per acre ..... do	1,766	4,063	2,937
Total annual cut (1917) ..... do	35,328,000	29,045,000	3,678,000
Total area annually cleared (1917) ..... acres	20,004	7,149	1,252
Total annual volume of stumpwood ..... cords	17,664	14,522	1,839

[1] From Forest Service records.

The commercial stands of yellow pine in Colorado are confined in a large measure to the national forests. They are scattered over nearly a million acres, but the volume to the acre is lower than that in any other State. It is not probable that any value may be derived from this stumpland in the way of distillation products.

The chief yellow-pine area in South Dakota is located in the Black Hills region. The average stand for the 707,000 acres is 4,063 board feet an acre, making the volume of stumpwood about two cords an acre, which is thought to be low for distillation purposes, as the wood is not especially resinous.

The stand in Wyoming is so small as to be entirely negligible for the purposes of distillation.

SUMMARY.

This brief survey shows that the quantity of stumpwood is enormous and that the problem of handling the cut-over areas is of first importance. It is known, however, that not all of these stumps are sufficiently resinous for profitable distillation, under present conditions.

TABLE 12.—*Annual lumber cut of western yellow pine in the United States (9).*

State.	Volume.				
	1914	1915	1916	1917 [1]	Stumpwood [2]
	Bd. ft.	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Cords.*
California	409,953,000	389,991,000	494,973,000	478,565,000	239,282
Oregon	210,438,000	189,203,000	399,102,000	470,488,000	235,244
Washington	175,426,000	148,789,000	188,215,000	220,924,000	110,462
Idaho	159,839,000	201,858,000	240,160,000	315,009,000	157,504
Montana	134,568,000	118,920,000	138,206,000	150,905,000	75,452
Arizona	78,667,000	75,843,000	92,133,000	78,147,022	39,074
New Mexico	54,728,000	61,466,000	72,004,000	76,149,793	38,074
Colorado	65,117,000	37,241,000	27,848,000	35,328,000	17,664
South Dakota	18,744,000	22,457,000	25,466,000	29,045,000	14,522
All other	19,885,000	6,476,000	6,880,000	8,354,000	4,177
Total	1,327,366,000	1,252,244,000	1,684,987,000	1,862,914,815	931,455

[1] From records of the district foresters.
[2] For 1917 only.

SUMMARY OF TABLE 12.

Total volume, 1914–1917, inclusive	(board feet)	6,127,511,815
Total area equivalent cleared, 1914–1917, inclusive, assuming 5,000 feet as average per acre	(acres)	1,225,502
Total stumpwood, 1914–1917, inclusive	(cords)	3,063,755

If the areas are not agricultural in character, they should be allowed to reforest. In this case the land-clearing problem is not so important, although the stumps should be utilized, if it is economically possible to do so. Table 12 shows that for the entire area of western yellow-pine land the average volume of stumpwood is 2.5 cords an acre, or 100 cords for every 40-acre tract. Probably half of this land carries double this amount of stumpwood. Be that as it may, it is certain that many thousands of cords of stumpwood must be removed before those who desire to make homes on the splendid yellow-pine lands, some of which are known to be among the best remaining lands obtainable for agriculture, can bring them into the proper state of cultivation and production.

PURPOSE OF INVESTIGATION.

In January, 1914, the Bureau of Chemistry, United States Department of Agriculture, in cooperation with the Department of Forestry of the University of Idaho, at Moscow, Idaho, began a study of the destructive distillation of logging and land-clearing waste in the State of Idaho, particularly of the yellow-pine stumps of that region. These investigations were instituted with the twofold purpose of ascertaining the feasibility of more effectively utilizing the timber resources of the Northwest and of reducing the net cost of clearing cut-over lands for agricultural purposes by the recovery of commercially valuable products from the stumps. The work resolved itself into determining (*a*) the nature, amount, and probable value of certain by-products obtained in clearing the land of stumps by

burning and the practicability of recovering these products by this method, and (*b*) the yield and value of products obtainable from yellow-pine stumpwood throughout the State when subjected to retort distillation.

The chief aim of the cooperative work was to determine the value for distillation purposes of western yellow-pine stumps and such other logging or land-clearing waste in the State of Idaho as might lend itself to the treatment. The abundance of yellow-pine waste is readily inferred from the volume of such lumber sent to market from mills throughout the State, and the relative abundance of yellow-pine stumps in any section can be ascertained from timber-cruise records, supplemented by the proper volume tables. The quality of the stumps with respect to their resin content, on which depends their value for distillation purposes, however, can not be determined from such field or timber-cruise data. The results of careful field inspections have led to the conclusion that much of the western yellow pine is of the relatively nonresinous or "bull pine" variety. Even the more resinous yellow-pine stumps varied so widely in their resin content that it soon became apparent that field investigations were indispensable to a proper knowledge of the proportion in which the various grades of stumps occur in the regions from which samples were collected. A knowledge of the conditions in the yellow-pine belt of the Atlantic and Gulf States made this all the more imperative, for the reason that the apparent preponderance of the lower grade of stumps clearly indicated that the profitable utilization by distillation of all yellow-pine stumps would be found impracticable, and that success in utilizing any of them would depend on a proper selection of material to be treated.

From an agricultural standpoint the object of the work was to determine the practicability of reducing cut-over land clearing costs through recovery of by-products from the stumps. The extent to which distillation products from the stumps can be made to defray the cost of clearing such land obviously depends, among other things, on the total number of stumps to the acre, the number of these stumps suited to distillation purposes, the yield and value of the by-products, and, finally, the cost of recovering these by-products from the stumps to be treated. The first of these probably can be fairly well established from timber-cruise records for regions in which such data are available; the second is a combined field and laboratory problem; the third a laboratory and trade inquiry problem; and the fourth a field and chemical engineering problem. The work accordingly resolved itself into an investigation involving each of these closely related problems.

TAKING SAMPLES.

In the spring of 1914, samples, with the attendant field data, were obtained from four acres in different parts of the State typical of the regions they were selected to represent, namely: (*a*) Cut-over land of a lumber company in Latah County, hereafter referred to as the Potlatch-Deary region; (*b*) the Coeur d'Alene and Hayden Lake region; (*c*) the South Idaho or Boise-Payette region; and (*d*) the Craig Mountain or Winchester region.

In these field-sampling operations a rapid reconnaissance trip was made to get a general idea as to the abundance and apparent quality of the stumps in a region. On the basis of such knowledge an area considered representative of the district was selected, from which samples representing the different qualities of stumps, together with data for an estimate of their relative abundance and number per acre, were taken.

In the beginning the stumps were arbitrarily classed as "rich" when the top showed a marked resinous exudation, or, if burned over, revealed decidedly resinous wood when cut into with an axe, as "medium" when it showed but little of such exudation, and as "poor" when, although apparently sound, it was devoid of any resinous exudation. All stumps containing little if any resinous wood are classed as "bull pine," despite the fact that this term is usually limited to the western yellow pine less than 24 inches across the stump.

Selected stumps of each class were removed by blasting, and only enough of their heartwood was taken to make, with wood from other stumps of the same quality, a cord sample of that class. This cord, or a smaller sample selected from this measured cord, was then shipped to Moscow for the experimental work.

In all cases the sapwood was split off and rejected; hence the results obtained in this investigation do not show what can be obtained from the whole stump of each quality, but only from the resinous heartwood. Because the western yellow-pine stumps ordinarily contained so little heartwood (on an average about 50 per cent), stumps under 24 inches were considered only when they contained larger proportions of the resinous heartwood. Such stumps, in later years, should the sapwood rot off while the heartwood remained sound and resinous, would then be practically 100 per cent resinous, but, of course, would yield a much smaller quantity of total wood.

Distinction between "yellow pine" and "bull pine."—The term "yellow pine" is here used to designate such members of the *Pinus ponderosa* group as contain an appreciable portion of relatively resin-

ous, dark-colored heartwood, compared to the sapwood layer. "Bull pine," although often large, has relatively no such high proportion of the richer resinous heartwood. Botanically, the "bull pine" is considered to belong also to the *Pinus ponderosa*, or western yellow-pine group, appearing to differ from the "yellow pine" only in being a less mature or more rapidly developed tree. Whatever may be the cause, the important fact remains that "bull-pine" stumps, aside from their content of what appears to be sapwood, are all but devoid of resinous matter and are utterly worthless for the recovery of turpentine or other distillation products (Table 14). "Bull-pine" stumps, irrespective of their size, therefore, are not included in the number of yellow-pine stumps to the acre in a given area or section, which makes it highly important to remember that no such distinction between these classes of stumpage is made by timber cruisers.

POTLATCH-DEARY REGION.

The southwest quarter of the southeast quarter of section 15, township 40 north, range 2 west, readily accessible and fairly representative of the number, size, and quality of stumps to the acre of yellow-pine land in the Potlatch-Deary section of the State, had had a yellow-pine stand of 395,000 board feet a "forty," averaging 500 feet a tree. The average yellow-pine stand for the township was 234,000 board feet to 40 acres.

The stumps were taken from a south slope, a ridge, and its adjacent lowland. The trees had been felled six or seven years before, and the stumps were generally found with all the bark. A few burnt-over stumps, of which the bark and sapwood had been destroyed, from trees said to have been dead when cut and in some cases felled for fuel wood 13 years earlier, were included. Ten stumps of each class were blown out and enough of the heartwood from each stump taken to make up a cord sample of each class. The stumps were removed by blasting with both 40 per cent and 20 per cent dynamite. Few of the stumps were removed entirely by the blast, most of them being either split through the middle, with only part of the stump thrown out, or left standing in a shattered condition. It was necessary, therefore, to employ a team of horses to remove enough of such shattered stumps to obtain a sufficient portion of each for the samples.

All of the heartwood of the first few stumps shot out was removed and split to approximately cordwood size, and a sample taken from each stump thus entirely reduced. The labor cost, estimated at from $4 to $5 a cord, made it so expensive, however, that only a portion of each stump sufficient to obtain enough for a sample was reduced. The diameters of the ten "rich" stumps varied from 24 to 40 inches, with an average of 32 inches; those of "medium" quality, from 26 to 36 inches, with an average of 30 inches; and the "poor" stumps,

from 24 to 36 inches with an average of 28 inches. The cost of shooting the 30 stumps was as follows (spring, 1914):

Two men, 2½ days, at $2.50 a day of 10 hours	$12.50
50 pounds of 20 per cent dynamite	7.50
165 pounds of 40 per cent dynamite	28.05
Fuses and caps	2.75
Total	50.80

Splitting the 30 stumps so as to obtain from each a sufficient portion for the sample required the work of 3 men for 3 days, which, at $2.50 a 10-hour day, amounted to $22.50. The cost of gathering and hauling the 3 cords of wood, requiring the services of 2 men and a 2-horse team for three-fourths of a day at $7.50 a day, was $5.62. If special stumping powder, selling for $12.50 a 100 pounds at that time, had been used, the powder cost could perhaps have been reduced by 20 per cent, or to $30 for the 30 stumps. The labor cost of placing the shot holes and shooting the stumps could probably be reduced on a steady job. Against this it should be said that to have removed all the stumps completely would have required the time of a man and a team of horses for an additional day, as well as extra powder, fuses, and caps. The labor cost of shooting the 30 stumps should accordingly be left at $12.50. To have split the stumps completely so as to recover all the heartwood and permit the handling of the pieces by 2 men would have taken the 3 men 3 days more, making the cost of splitting the 30 stumps $45. On a steady job with men accustomed to the work, provided with tools or equipment that experience would suggest, this item possibly could be reduced by at least 50 per cent, or, in this case, to $22.50. On the basis of an average of 50 per cent heartwood in the stumps, it is estimated that at least 3 stumps are required to make a cord of wood, or about 10 cords from the 30 stumps. To gather up, haul, and load this on the car would cost 10/3 times $5.62, or $18.73. Summing up on this basis, the cost of these 10 cords of wood loaded on the car after a 1-mile haul is:

Powder, fuse, and caps	$30.00
Shooting	12.50
Splitting	22.50
Gathering and hauling	18.73
Total	83.73
Cost a cord	8.37

Liberal allowances have been made in the items on which the cost of this yellow-pine stumpwood depends, and the cost a cord is confidently believed to be a minimum one. A material reduction of this figure need be expected only from the use of hitherto undeveloped

land-clearing methods, from a failure on the part of the farmer to charge the value of his time and equipment in shooting, reducing, and hauling the stumps against the cost of the wood so delivered, or from a decided reduction in the selling price of explosives or in labor.

The conclusions based on this method of sampling were subsequently checked by removing all the yellow-pine stumps on a typical acre, taken to represent a good stand of large yellow pine in the Potlatch-Deary yellow-pine region, in the southwest quarter of the southeast quarter of section 36, township 42 north, range 5 west. The yellow-pine stand on this "forty" was 540,000 board feet, of which 240,000 board feet were from trees averaging 700 feet a tree, and 300,000 board feet from trees averaging 2,500 feet a tree. This figures out to a stand of 9 of the smaller trees containing a total of 6,000 feet and 3 large trees containing a total of 7,500 feet, or a total of 13,500 feet an acre. Of the 12 yellow-pine stumps on this chosen acre, 9 averaged 30 inches and 3 averaged 45 inches in diameter. The proportion and quality of the heartwood were so markedly different in the large stumps, as compared with that in the small stumps, that the woods from the large and small stumps were collected separately as two samples, and are hereafter referred to as "large" and "small" yellow-pine stumps, Potlatch, Idaho.

A sample taken from so-called "rich butts," "tops," etc., was collected throughout the area from which the stumps at Deary were obtained, where a large amount of this material is available in the form of dead standing trees and windfalls. Judged by its appearance, little, if any, of it is rich in resinous matter. Hence one sample only, designated in the tables as "dead, down wood," was selected from the richer material of this class.

COEUR D'ALENE AND HAYDEN LAKE REGION.

The Coeur d'Alene and Hayden Lake region, taken as being representative of cut-over yellow-pine lands in northern Idaho, proved to be an unwise selection, as a larger proportion of "bull pine" or nonresinous material was found there than in the Pend d'Oreille River country farther to the north. It should be considered typical rather of the yellow pine in the territory within a 50-mile radius of Spokane. Two yellow-pine samples were taken, one on a ranch some 2 miles northwest of Hayden Lake towards Garwood, the other from the Mica Bay section of Coeur d'Alene Lake. The first was representative of the average quality of yellow-pine stumps proper in the Hayden Lake region, few, if any, of which showed resinous exudation, and approximated 20 to 35 an acre in the closest yellow-pine stand of this region, which had been cut over a few years before.

The sample collected at Coeur d'Alene Lake was from "rich" stumps on a 20 to 30 acre tract near Mica Bay, not yet brought under cultivation. Stumps of the quality represented by the sample do not occur in commercial quantities in the Coeur d'Alene Lake region.

SOUTH IDAHO REGION.

The wooded country throughout the South Idaho region is practically undeveloped and without railroads. The forests remain untouched, except in a few places where small-scale logging operations have been carried on to supply local mills. The timber resources are now being opened up for extensive logging operations to supply a mill of about 200,000 feet daily capacity at Barber, some 6 miles out from Boise.

Working out from this company's logging camp, about 35 miles northeast of Boise, a hasty survey was made of an area which had been cut over in places 7 or 8 years before the company had taken over the land or timber rights. Although the timber throughout this region is largely yellow pine, few of the stumps appeared pitchy enough to be considered "rich." Fully 50 per cent were unsound and therefore worthless for distillation purposes. The stand of yellow-pine trees or stumps 24 inches or more in diameter is estimated as not exceeding an average of 10 an acre. The actual count for several 1-acre plots, taken to represent a close stand, was 20, 22, and 18 trees, respectively. Three 1-acre plots taken to represent a stand of medium density ran 10, 6, and 9 trees an acre. Toward the other extreme the stand diminished to where, on the higher ridges, no yellow pine was encountered.

According to one of the company's cruisers, the whole of the Boise-Payette pine belt is very much like the land traversed, and an estimate of 10 yellow-pine trees, over 24 inches in diameter, an acre is liberal.

Of the total number of yellow-pine stumps on a given area in the old cuttings perhaps 1 out of 25, or not to exceed 5 per cent, may be considered as belonging to the "rich" or "pitchy" class, probably 40 to 50 per cent are of "medium" quality, and the remainder of a quality from which it was not considered worth while to take a sample. Four samples were taken: (*a*) One from old cuttings to represent the "rich," or "pitchy," stumps; (*b*) one of "medium" quality, from the old cuttings; (*c*) one from green stumps from which the tree had been felled within a month of the time the stumps were shot; and (*d*) one of green "bull-pine" stumps. Samples *c* and *d*, included because they were the stumps and logs from freshly fallen trees, though containing no well-defined heartwood, had an abundant exudation of what appeared to be gum on the freshly cut

surface. There was a little dead, down wood, and, as the tops of freshly fallen trees did not appear to be essentially different from those seen elsewhere and were obtainable nearer Moscow, a sample of this wood was not taken. It was difficult to judge the relative quality of the green stumps other than by the proportion of heartwood to sapwood, the apparent resin content of the heartwood being quite uniform. The proportion of truly resinous heartwood to sapwood varies greatly, however, a matter of importance in considering the value of the stumps, owing to the dearth of resin in the sapwood. Probably 50 per cent of the green yellow-pine stumps are of the quality represented by sample, and the remainder of inferior quality, in so far as the proportion of heartwood to sapwood is concerned.

It would be very difficult to remove these stumps unless they were taken out with the logging operations, because of the fact that the mountainous topography and limited rainfall preclude an extensive agricultural development in the wake of the logging operations. The surface of the land presents an irregular series of steep ridges between which wind deep, narrow valleys, where spur tracks are laid for the logs which are skidded down the hillsides to be loaded on tracks, moved as fast as the logs are taken away. The stumps, therefore, become inaccessible as soon as the tracks are taken up.

CRAIG MOUNTAIN REGION.

The yellow pine of the Craig Mountain region is a practically pure stand over an area some 10 miles long by 5 miles wide on an elevated, fairly level plateau. Receding from this central area the timber opens abruptly on Mission Canyon and the prairie country toward the north and west, and less abruptly toward the east, while toward the south it soon becomes mixed with fir and tamarack in the Salmon River country. A lumber mill with a daily capacity of about 125,000 feet operates in Winchester, which is centrally located in this yellow-pine belt. Comparatively little of the timber had been cut.

In the central pine area the stand of yellow pine varied from 400,000 to 800,000 board feet a "forty," with an average of approximately 20 stumps over 30 inches in diameter an acre where the stand was closest. The mill men and cruisers consulted agreed that probably 25 per cent of the total stand throughout this region is "bull pine."

Seven samples were taken from this region, as follows: (*a*) Green yellow-pine stumpwood from several stumps blown out of the roadbed in extending spur tracks for logging purposes; (*b*) medium to rich stumpwood from stumps blown out in highway construction; (*c*) medium to poor stumpwood from the same locality in which the medium to rich samples were obtained; (*d*) medium to

rich stumpwood shot on land that had been cut over 4 or 5 years before; (*e*) dead, down yellow-pine wood collected from the better quality of knots, limbs, and trunks of trees lying throughout the woods; (*f*) rich, dead tops from trees felled in logging operations, the tops of which were dead from advanced maturity, and dead standing trees that had died from the same cause; (*g*) the better quality of tops and limbs from freshly felled trees. In addition, certain other samples were included in the investigation. The sample designated "rich stumpwood, Viola" was from western yellow-pine stumpwood, from a ranch located near Viola. These stumps, the last of those remaining scattered through the field, had been shot out with dynamite, and the best snaked to the house for fuel. It was from this lot, the weight a cord of which was estimated to be 3,500 pounds, that a sample was taken. Trees cut from these stumps were said to have been felled 35 or more years before. The wood was very resinous, and to all appearances the same as the better grades of pitch pine of North Carolina or other southern States.

The sample 30-inch stump from Priest River, obtained from a single large yellow-pine stump sent in from Priest River, Idaho, was selected as representing the best of the rich, or pitchy, stumps in that region. It had been blown out with dynamite, and the whole stump, roots and body, split into several pieces by the blast, was weighed, split, and reduced to stove-wood size. It was then mixed by being thrown together in a heap and repiled five or six times, after which it was neatly stacked under a shed. Dimensions of the pile of wood thus stacked were 8x7x1.5 feet, equal to a volume of 84 cubic feet. The stump weighed 2,190 pounds, so that as piled this wood weighed $\frac{2{,}190 \times 128}{84}$, or 3,330 pounds a cord, in round numbers. The tree cut from this stump had been felled about seven years, not long enough for the sapwood to have rotted away or become detached from the lightwood within. This sapwood contained absolutely no turpentine and impoverished the wood to that extent. It is estimated to have constituted 20 per cent of the total volume of wood in the stump.

The samples identified in Table 14 as "dead, down limbs" and "fire-scarred butts, Viola" were from yellow pine taken near Viola. Both samples were very resinous for these classes of wood. There was not a sufficient quantity of either to determine closely the weight of a measured cord. Nevertheless, if these facts are borne in mind and these samples are considered with other samples of the same classes of wood, they furnish an indication of the products to be recovered from these materials, which are quite plentiful in some sections. In some regions as much as 20 per cent of the butt logs

are fire scarred. The values on these samples given in Table 14 are, therefore, only estimates.

SUMMARY.

Northern Idaho:
- Rich stumpwood, Priest River.

Potlatch-Deary Region:
- Rich stumpwood, Viola.
- Dead, down limbs, Viola.
- Fire-scarred butt, Viola.
- Poor stumpwood, Deary.
- Rich stumpwood, Deary.
- Medium stumpwood, Deary.
- Dead, down limbs, Deary.
- Rich stumpwood, Potlatch (three large stumps).
- Medium to rich stumpwood, Potlatch (from stumps other than the three large, rich stumps).

Coeur d'Alene Region:
- Rich stumpwood, Coeur d'Alene Lake.
- Medium stumpwood, Hayden Lake.

South Idaho, Boise Region:
- Bull-pine stumpwood, Boise.
- Medium stumpwood, Boise.
- Rich stumpwood, Boise.
- Green selected stumpwood, Boise.

Craig Mountain Region:
- Selected green stumpwood, Craig Mountain.
- Rich roadside stumpwood, Craig Mountain.
- Medium stumpwood, Craig Mountain.
- Rich, cut-over stumpwood, Craig Mountain.
- Dead, down limbs, etc., Craig Mountain.
- Dead tops, limbs, etc., Craig Mountain.
- Green tops, limbs, etc., Craig Mountain.

Moscow:
- Tamarack stumpwood.

DISTILLATION OF SAMPLES.

PREPARATION.

The wood as delivered was sawed in lengths that would fit into a pile of cord dimensions and split into pieces approximately 2 to 4 inches in diameter. It was then thrown into a heap, repiled a sufficient number of times to render it uniform in quality, corded, taking care to pack closely, and left standing, protected from the weather, until run. The entire sample thus prepared was weighed on a portable platform scale immediately before the distillation, and the weight calculated from its measured dimensions. In making these weighings 3 separate portions, usually of 175 pounds each, were taken from throughout the entire pile in such manner as to make sure that each sample was truly representative of the original field sample.

When a cord of wood is split into smaller pieces and again corded its volume is increased because of the greater proportion of voids

or air spaces, the weight decreasing as the cubical content increa
An increase of about 10 per cent is said to result from reduc
average cordwood to the size in which the wood making up
samples used in this work was piled and measured, from wl
it would appear that the weights per cord on which the yields
computed should be increased by 10 per cent. Owing, however
the irregular shape of the pieces of stump cordwood and the
observed in piling the reduced wood closely, it is believed that
observed weights are not essentially lower than the average we
of a commercial cord of western yellow-pine stumpwood of co
sponding quality. In support of this it was found that of tl
cords of stumpwood from near Deary, Idaho, piled and measu
in the field, when corded again after having been reduced to
size in which they were used in the retort, one measured an
cord, one 19 per cent less than a cord, and the third 10 per
more than a cord. It seems unnecessary, therefore, to use o
than the observed weights in calculating results.

The retort distillations were made on charges of known weig
varying from 150 to 200 pounds, depending on the nature of
wood. The distillation products were measured in liters per ch
and the yields reported in gallons per cord. This basis of st
ment was selected in preference to the more exact unit-of-we
basis, the ton, for example, because of the difficulty of estima
the quantity of the several classes of wood on a given acre
applying the results to the problems in hand on other than
cord basis. The yields can be quickly figured to the ton basis f
the data given in Table 14.

APPARATUS.

In principle, the apparatus (figs. 3 and 4) is essentially an
jacketed retort (*a*) in which high-flash cylinder oil, heated to
desired temperature, is circulated through closely spaced hea
coils (*b*, *c*, and *d*) within the retort. The coil system of jacke
is preferable to a double shell in that it insures a positive flo
the heated oil, and, by dividing the coils into sections, prevent
excessive drop in temperature between the incoming and outg
oil. A 3-inch layer of asbestos lagging and pipe covering of
same material protects the retort and exterior piping against
cessive radiation. A coarse wire-gauze screen placed on the ja
coils facilitates removal of the charcoal.

The motor-driven oil pump (*f*) takes oil from the overflow
(*g*) and discharges it through the gas-fired oil heater (*e*) into
jacket coils (*b* and *c*), from the other end of which it flows
into the tank (*g*). This circulation is maintained with the jacke
as it comes from the heater and is held at 260° C. as registere

thermometer 1 until the turpentine has been recovered. The temperature is then raised to 343° C., and the bottom coil (*d*) made to join in the circulation of the oil by opening valve *o* until destructive distillation of the charge has been effected. Valves *m*, *n*, and *o* are adjusted (ordinarily unnecessary) so that thermometers 2, 3, and 4, registering the temperature of the return oil from coils *b*, *c*, and *d*, respectively, read essentially alike, indicating thereby that the oil flows equally through the three coils.

PROCEDURE.

Turpentine is present in resinous wood, along with rosin, as an oleoresin. Subjected to the designated retort temperature this oleoresin is partially sweated out and escapes from the pores of the wood, losing the turpentine by vaporization, while the resin accumulates

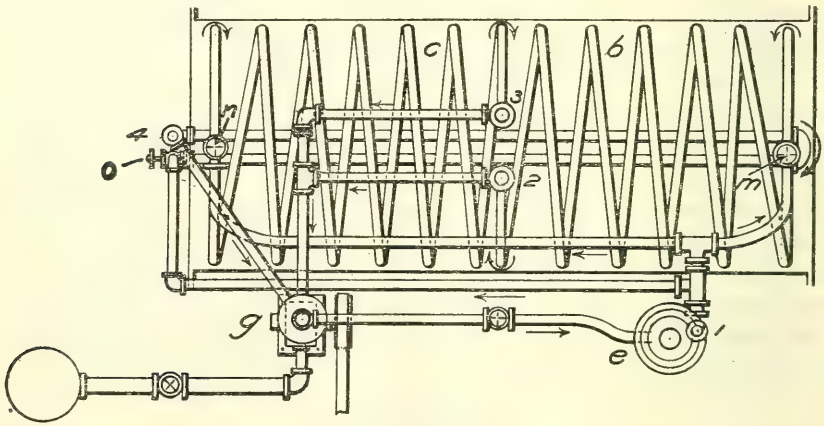

FIG. 3.—Plan of retort used for distillation of samples.

with certain decomposition products, as pitch, in the bottom of the retort. The distillation is therefore conducted in two stages.

During the first stage the turpentine is recovered, and the resulting rosin liberated from the wood is collected in the bottom of the retort. The oil-bath temperatures during this stage are between approximately 220° and 265° C. The valve to the bottom coil (*d*) that lies embedded in the molten rosin is then opened, and the temperature of the circulating oil raised to 343° C. This brings about destructive distillation of the wood and the rosin, with the production of pyroligneous acid and the formation of rosin oils containing also creosote and other constituents derived from the wood, which distil from the retort in two stages as light oil and heavy oil.

The light and heavy oils come over with the aqueous distillate (pyroligneous acid) resulting from the chemical transformation of the wood and rosin during the destructive stage of the distillation,

the light oil between 260° and 330° C., and the heavy oil above 330° C. A strong evolution of wood gas, which burns with a bright luminous flame, takes place while the heavy oil comes over. Charcoal and pitch are the end products of the distillation. The pitch is drawn off through a plug cock in the bottom of the retort at the end of a run. There is no sharp line of demarcation between the stages in which the distillation is conducted, because decomposition of the wood takes place long before all the turpentine has distilled over, and to effect a maximum recovery of it this stage of the distillation

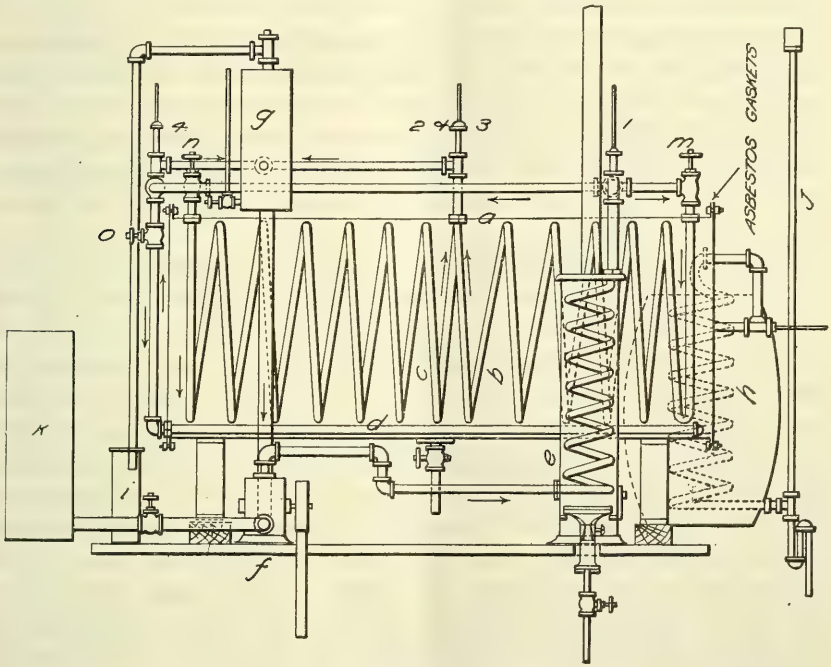

FIG. 4.—Elevation of retort.

a, Retort shell.
b and *c*, Main heating coils.
d, Bottom heating coil.
e, Oil heater.
f, Oil circulating pump.
g, Overflow tank.
h, Worm condenser.
j, Trapped vent pipe.
k, Oil tank.
l, Overflow catch.
m, *n*, *o*, Valves.
1, 2, 3, 4, Thermometers.

must be continued to the point at which the wood is converted into a brown friable substance approaching charcoal in its nature. This decomposition sets in when most of the hygroscopically held moisture has been expelled from the wood (about 260° C.), and is made apparent by the sharp odor of the distillate and development of a reddish color in the hitherto colorless aqueous layer. This incipient decomposition is soon attended by a perceptibly acid taste of the distillate, turbidity of the turpentine layer, and the escape of noncondensable gases (mostly carbon dioxid) from the vent pipe (*j*). This point in

the distillation can be distinguished by an experienced person within fairly close limits by means of the changes indicated.

Contamination with decomposition products and the proportion of heavier oils, that subsequently must be removed, increase rapidly beyond this point. This comparatively pure fraction, therefore, is not allowed to mingle with that coming over beyond this point, but is collected separately as "first crude turpentine," while the remainder constitutes "second crude turpentine." The aqueous distillate coming over with the first crude turpentine, being practically free from alcohol and acid, is discarded, but that from the second turpentine is collected and saved with the pyroligneous acid obtained throughout the remainder of the run. The temperature being held fairly constant, the second turpentine fraction is continued to the point where the flow of distillate from the condenser drops below a practical limit, equivalent to about a gallon a half hour in these experiments, and the oil passing over no longer contains turpentine, as shown when it is dry distilled.

Along with the drop in speed of condenser discharge, the distillate suddenly takes on a true consistency and undergoes such a characteristic change of odor that there is no mistaking the point at which all turpentine has passed over. By the time combustible gases that burn with a pale blue flame begin to escape from the vent pipe. The bottom coil is then opened and the temperature of the jacket oil run up to approximately 345° C., where it is maintained until the end of the distillation. The oil becomes heavier as the temperature rises, until presently it separates from the aqueous portion of the distillate only after standing for some time. This marks the end of the "light-oil" period. The greater viscosity of the heavy oil and its characteristic odor are further relied on in cutting the light and heavy oil fractions. The discharge of noncondensable gases now reaches a maximum, and these suddenly burn with a bright luminous flame in place of the one hitherto blue.

RESULT OF DISTILLATION.

The products obtained by this method of destructive distillation are, therefore, seven in number: Crude first turpentine, crude second turpentine, light oil, heavy oil, pyroligneous acid, pitch, and charcoal. The temperatures and the volumes of oil and acid distillate collected were entered every half hour in a log kept of each charge (Table 13). The distillates were collected in large graduated cylinders and the oil removed from the aqueous layer in separatory funnels. The sum of the half-hour oil readings tends to be a little high because of the imperfect separation of the water and the volume of the oil accumulated by the end of the period a little low because

of unavoidable transfer losses. The mean of the two, therefore, is used in calculating gallons a cord.

TABLE 13.—*Specimen log of a run of 150 pounds of Boise medium yellow-pine stumpwood.*

Time.	Temperature of oil bath.	Products obtained.		Combined oil and water.	Remarks.
		Oil.	Water.		
A. M.	*° C.*	*Cc.*	*Cc.*	*Cc.*	
8.25	.....	.....	.....	.....	Lighted gas, started pump, closed bottom coil.
10.00	223	.....	.....	.....	Distillate started.
10.30	238	410	790	.....	
11.00	250	540	1,100	.....	
11.30	260	500	940	.....	
12.00	261	495	800	.....	Took sample acid liquor for analysis.
12.30	256	430	640	.....	Noncondensable white vapors first appeared; last of first turpentine.
P. M.					
1.00	261	360	485	.....	First of second turpentine; began saving acid liquor.
1.30	261	385	530	.....	
2.00	261	370	570	.....	
2.30	260	300	590	.....	Gas from vent-pipe burns.
3.00	260	235	590	.....	
3.30	263	180	570	.....	
4.00	258	160	560	.....	Last of second turpentine; ran up temperature; opened bottom coil.
4.30	281	135	490	.....	First of light oil.
5.00	298	165	560	.....	
5.30	310	170	830	.....	
6.00	319	380	1,550	.....	
6.10	322	230	740	.....	Last light oil.
6.30	327	.....	.....	3,050	Heavy oil started.
7.00	336	.....	.....	4,050	
7.30	340	.....	.....	2,050	
8.00	344	.....	.....	1,550	
8.30	346	.....	.....	1,100	
9.00	342	.....	.....	600	
9.30	342	.....	.....	240	
10.00	342	.....	.....	90	Shut down, drew pitch; drip 150 cc. heavy oil by next morning.

CHARACTER OF CHANGES OCCURRING DURING DISTILLATION.

Wood tissue is made up primarily of cellulose, which, built up into cells and tissue, constitutes the structural element of plants, and lignin, which occurs as an incrusting matter or coating on the cell walls. In resinous wood there is a further deposit in the wood tissue of oleoresin from which the turpentine and pine oils are obtained when the wood is subjected to distillation at a relatively low temperature.

As previously explained, the nonvolatile substance remaining when the volatile oils are distilled from the oleoresin is rosin, a substance largely composed of abietic acid. Toward the end of the turpentine stage of the distillation the contents of the retort may be considered as made up principally of abietic acid, cellulose, and ligninlike substances, all of which are composed of the elements carbon, oxygen, and hydrogen. The molecules of these substances, being comparatively large and complex, are readily broken down by the application of heat into a series of simpler compounds, some of which, reacting the one on the other, may form still other com-

pounds. Of them all, water is the compound formed in the greatest quantity, because of the fact that oxygen and hydrogen constitute 55 per cent of cellulose, the principal wood constituent. This water, holding in solution numerous other compounds, produced simultaneously with its formation, is referred to in this bulletin as the "acid liquor," an exceedingly complex liquid of a wine-red color, having a sharp, tarry odor and strong acid reaction. In addition to water, it is largely made up of acetic acid, methyl or wood alcohol, tar acids, oils, esters and acetone aldehyde bodies, together with small proportions of numerous other compounds of an unknown nature.

It is not meant to convey the idea that these changes occur in clear-cut stages. Neither is it strictly true that the charge in the retort is in reality made up of cellulose, lignin, and abietic acid or rosin at any time during the distillation, for these compounds, owing to their instability toward heat when dry, undergo progressive changes as the moisture is more and more completely driven out of the wood, before the recovery of turpentine is complete. Though the period during which the distillation products do not result from decomposition of the wood substances and the destructive stages of the distillation merge into each other or overlap, the nature of the changes taking place is essentially as set forth.

Distillation of Wood (Exothermal) and of Rosin (Endothermal).

The chemical reactions brought about during the destructive distillation of cellulose are exothermal, that is, heat is given off during the changes taking place once the action, for which a temperature of 270° C. is necessary, has been started. The amount of heat thus liberated was found by Klason, Heidenstam, and Norlin[5] to be equivalent to 4.6 per cent of the calorific or fuel value of the wood (pine). The reactions involved in the decomposition of rosin by destructive distillation, in the course of which rosin oils are formed, however, cease unless an adequate supply of heat is maintained throughout the distillation. This is due to the fact that the changes taking place, instead of liberating, take up heat, being "endothermic" reactions.

These facts are of significance in view of the difference in behavior observed when the more highly resinous wood and that containing but little resinous matter, such as "bull pines," are distilled. In the case of the more highly resinous wood a decided exothermic effect was observed while the destructive stage of the distillation was in progress, continuance of the high temperature (343° C.) being necessary to carry the distillation to completion. In the distillation of "bull pine" in the same state of dryness, however, the reaction be-

[5] Arkiv. Kemi. Min. Geol., Band 3, No. 10, Heft 2. Published by the Royal Academy of Sciences at Stockholm.

came so violent when a temperature of about 300° C. was reached that the distillation could practically be completed without further heating, and in less time than the richer wood with continued heating.

It was necessary, therefore, in distilling the "bull pine" to watch the oil-bath thermometer carefully in running up the temperature for destructive distillation and turn off the heater flame when this period was reached. The reaction progresses so rapidly that the discharge of gas and vapors may exceed the otherwise ample condenser capacity, and loss of distillate result from imperfect condensation. The difference in behavior is due to the fact that the richer wood contains a much greater ratio of rosin to cellulose. The heat set free during decomposition of the wood substance is more than offset by that required to effect decomposition of the rosin in such wood, and additional heat must be supplied to insure the decomposition of rosin and the distillation of the products.

The fact that in the destructive distillation of nonresinous woods enough heat above a certain temperature is developed to complete the distillation without the application of heat from outside sources, necessitates the installation of larger condensers in the distillation of nonresinous woods than are needed in the distillation of resinous woods. When the exothermal reaction begins, it proceeds so rapidly that the condensers, which in the earlier stages were large enough to condense all condensable material, can no longer do so, and a loss of valuable products occurs if the condensers are too small to meet all the requirements that may be placed upon them during the exothermal period.

Yields.

The yields of crude products obtained in the retort distillation, and of the refined turpentine and pine oil for each sample, are given in Table 14. A summary of these tabulations, giving the average recovery from the various grades of wood distilled, is given in Table 19.

TABLE 14.—*Results of destructive distillation of Idaho western yellow pine.*

(Expressed in units per cord.)

Grade.	Kind and source of wood.	Weight per cord.	Crude products.							Steam-refined products from crude turpentines.									Final merchantable products.	
			Turpentines.							First turpentine from—			Second turpentine from—			Pine oil fraction from—				
			First.	Second.	Light oil.	Heavy oil.	Acid liquor.	Pitch.	Charcoal.	First crude.	Second crude.	Total.	First crude.	Second crude.	Total.	First crude.	Second crude.	Total.	Turpentine.	Pine oil.
		Lbs.	*Galls.*	*Galls.*	*Galls.*	*Galls.*	*Galls.*	*Lbs.*	*Lbs.*	*Galls.*	*Galls.*	*Galls.*	*Galls.*	*Galls.*	*Galls.*	*Galls.*	*Galls.*	*Galls.*	*Galls.*	*Galls.*
Rich	Stumpwood, Viola	3,500	17.1	17.8	8.3	70.5	72.6	164	966	13.3	7.9	21.2	0.7	2.3	3.0	1.7	2.6	4.3	25.7	3.1
Do	Stumpwood, Priest River	3,300	14.8	11.4	4.0	48.0	74.4	110	988	11.8	5.2	17.0	.6	1.3	1.9	1.1	1.2	2.3	19.5	1.7
Dead, down [1]	Rich, dead, down limbs, Viola	3,000	17.8	13.5	4.9	47.0	61.9	104	850	13.6	2.9	16.5	1.3	1.9	3.2	1.6	2.8	4.4	21.0	3.1
Medium [1]	Fire-scarred butt, Viola	2,400	7.1	6.4	.....	.....	.....	.....	.....	5.1	1.5	6.6	.8	1.0	1.8	1.1	1.0	2.1	8.9	1.6
Poor	Poor stumpwood, Deary	2,100	6.9	6.8	2.9	23.6	59.4	83	714	5.7	2.8	8.5	.4	.7	1.1	.3	.6	.9	9.7	.8
Rich	Rich stumpwood, Deary	2,600	14.9	13.0	4.9	44.6	55.9	232	670	12.9	6.5	19.4	.6	1.8	2.4	.9	1.6	2.5	22.4	1.9
Medium	Medium stumps, Deary	2,200	9.3	8.9	2.8	31.7	54.3	140	651	7.5	3.6	11.1	.4	1.5	1.9	.6	1.2	1.8	13.4	1.4
Dead, down [1]	Dead, down, Deary	2,200	6.3	5.2	3.3	25.7	53.4	92	863	4.7	2.1	6.8	.4	.7	1.1	.5	.8	1.3	8.2	1.0
Rich	Rich stumps, Coeur d'Alene	2,800	16.5	12.7	3.7	51.5	60.9	237	736	13.2	5.6	18.8	.9	1.7	2.6	1.2	2.0	3.2	22.3	2.3
Medium	Medium stumps, Hayden Lake	2,200	6.8	6.9	2.8	25.8	61.4	104	722	5.4	3.0	8.4	.4	.9	1.3	.5	1.0	1.5	10.1	1.1
Do	Bull-pine stump, Boise	1,900	1.6	.....	1.0	12.2	64.3	.....	688	.6	.....	.6	.2	.....	.2	.3	.....	.3	.9	.2
Do	Medium stumps, Boise	2,400	9.0	8.8	4.9	24.8	63.9	188	800	7.7	4.4	12.1	.5	.9	1.4	.3	.9	1.2	13.7	1.0
Rich	Rich stumps, Boise	2,500	14.5	10.7	4.1	44.9	59.5	230	693	12.2	5.3	17.5	.6	1.5	2.1	.9	1.3	2.2	20.1	1.7
Green	Selected green stumps, Boise	2,400	9.9	5.0	3.2	32.1	63.6	144	768	8.1	2.5	10.6	.7	.5	1.2	.3	.5	.8	11.8	.8
Do	Selected green stumps, Craig Mountain.	2,500	8.7	7.4	2.5	30.1	69.2	143	823	7.2	3.8	11.0	.4	1.0	1.4	.5	.4	.9	12.5	.8
Rich	Roadside rich stumps, Craig Mountain.	2,600	13.4	7.6	2.7	42.3	63.6	160	770	10.0	3.4	13.4	1.0	1.3	2.3	1.1	1.1	2.2	16.2	1.7
Medium	Roadside medium stumps, Craig Mountain.	2,300	9.9	7.2	2.8	25.9	66.6	119	673	7.3	2.9	10.2	.6	1.0	1.6	1.1	1.0	2.1	12.3	1.6
Rich	Cut-over rich stumps, Craig Mountain.	2,500	13.3	8.0	3.7	36.6	62.4	214	752	10.7	3.2	13.9	.6	1.1	1.7	1.1	1.1	2.2	16.2	1.6
Dead, down	Selected dead, down, Craig Mountain.	2,400	4.5	2.8	2.8	22.2	75.8	42	778	2.6	.8	3.4	.6	.4	1.0	.6	.4	1.0	4.6	.8
Do	Selected dead tops, Craig Mountain.	2,000	5.9	3.7	3.3	19.5	63.2	98	671	4.8	1.6	6.4	.3	.3	.6	.3	.3	.6	7.2	.4
Green	Selected green tops and limbs, Craig Mountain.	2,400	3.1	2.8	3.3	16.1	80.8	22	764	2.0	1.1	3.1	.3	.3	.6	.2	.3	.5	3.8	.4
Do	Tamarack stump, Moscow	2,500	.2	.....	.....	6.5	74.1	.....	803	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Rich	Large rich stumps, Potlatch	2,700	14.5	7.6	5.1	29.5	65.7	155	736	10.3	3.1	13.4	1.3	.9	2.2	1.6	1.1	2.7	16.3	2.0
Medium	Heartwood, small stumps, Potlatch.	3,000	12.1	10.5	4.8	24.4	74.4	102	.....	9.7	6.1	15.8	.7	1.2	1.9	.7	.9	1.6	18.0	1.3

[1] Exceedingly scarce; can not be considered as a source of wood for distillation purposes in itself.

CRUDE PRODUCTS OF RETORT DISTILLATION.

CRUDE WOOD TURPENTINE.

The crude wood turpentine is distilled from the wood during first stage of the destructive distillation. During this first stage distillation the turpentine passes over for the most part unchang as it probably exists in the wood tissue. The crude first turpenti therefore, is nearly free from pyroligneous bodies. It is often li in color, and usually possesses an agreeable odor. It has a spec gravity of about 0.875 at 20° C., a refractive index of about 1.4 at the same temperature, and an initial boiling point of about 164°

The crude second turpentine necessarily contains more of the py ligneous or heat-decomposition products and of the heavier pine c since the retort operator cuts the distillate at the first signs of composition of the wood, indicated by the appearance of nonc densable gases, and collects the remainder of the turpentine as "s onds." The heat-decomposition products of the rosin and w constituents consist of acids, alcohols, ketones, phenols, aldehy etc., the nature and quantity of which depend on the temperat and rate at which the turpentine stage of the distillation is conduct This crude second turpentine is darker than the crude first, and color is sharper and more suggestive of wood decomposition. It a specific gravity of about 0.910 at 20° C., a refractive index of ab 1.4850 at the same temperature, and an initial boiling point of ab 130° C. (due to the presence of decomposition products).

The difference between these two crude turpentines is well set fo in Table 15.

TABLE 15.—*Products of dry distillation of crude turpentine at 760 mm. press*

Temperature of distillation (° C.).	First turpentine.	Sec tur ti
	Per cent.	*Per*
Below 170	9.3	
Between 170 and 175	52.8	
Between 175 and 180	16.0	
Between 180 and 185	.....	
Residue	21.9	

The details of refining the crude turpentine are discussed page 56.

LIGHT OIL.

The crude light oil is brownish black, has a sharp, penetrati empyreumatic odor, an average specific gravity of about 0.995 refractive index of 1.514, each at 20° C., and an acid value of ab 29. Its average viscosity at 25° C. is 2.58° Engler. The yield about 4½ gallons a cord of rich wood. Distilled in the ordin manner at atmospheric pressure, using a fractionating column has an uncertain initial boiling point, around 70° C., due to the p

ence of water and other low-boiling constituents, which rises rapidly to 160° C. The complex nature of this material is indicated by its wide temperature range when subjected to distillation. Typical results are shown in Table 16.

TABLE 16.—*Distillation data of composite crude light oil.*

Material distilling between—	Amount.	Material distilling between—	Amount.
	Per cent.		*Per cent.*
55° and 120° C.	3.5	230° and 350° C.	54.3
120° and 180° C.	13.6	Watery layer	1.8
180° and 230° C.	21.1	Residue soft pitch	5.7

On subjecting the various samples of crude light oil to dry distillation at atmospheric pressure, using a fractionating column, an average of 34.5 per cent was found to distil below 225° C. Of the total distillate an average of 1.8 per cent was aqueous. This aqueous portion, as well as the lighter portions of the oily distillate, contains quantities of acetic acid, methyl alcohol, and acetone. The difficulty of their recovery in a state pure enough for quantitative estimation is such, however, that it is as yet possible only to estimate the quantities of these bodies present.

On treating the distillate obtained below 225° C. with an excess of 20 per cent alkali solution, a marked contraction in volume of the oil and decided heating were observed. When the oil thus treated was steam distilled to exhaustion, 87 per cent (1.3 gallons a cord) of total distillate was recovered as a rather sharp-smelling, light-yellow oil having an uncertain initial boiling point of about 125° C. On dry distilling this steam-distilled oil, 60 per cent passed over below 175° C., and the remainder distilled up to 250° C. In its behavior on distillation it shows a close resemblance to rosin spirits.

By treating the crude light oil with alkali and distilling with steam as in the refining of the crude turpentine, 10 per cent (0.4 gallon a cord) of the oil is recovered as refined rosin spirits distilling at from 130° to 200° C. and 20 per cent as a pine-oil fraction distilling at from 175° to 275° C. The pine-oil fraction distilling at from 175° to 275° C. has a lemon-yellow color like refined pine oil, but an unpleasant, altogether different odor, and can not be considered as pine oil, except perhaps in certain of its constituents. Fifty per cent of it distils below 200° C.

The residue from this steam distillation of the crude light oil forms a heavy emulsion with the alkali present. On the addition of acid about 10 per cent of the original oil separates out as a heavy tar that settles to the bottom. The remaining oil has about the density of water, slowly floating to the top, is dark, and has a mild odor.

Distilled in a vacuum of from 10 to 20 mm., 80 to 85 per cent (3.2 to 3.4 gallons a cord) of the crude light oil is recovered as a

clear, brownish-red oil that darkens on standing and has a creosote odor. The residuum from this distillation is a hard pitch. Repeated rectification of this light oil has given a series of fractions ranging from 166° to 176°. The fraction from 174° to 176° gives an oily bromin addition product. Apparently it adds hydrochloric acid gas to form needlelike crystals after standing a number of days, but all attempts to make a nitrosyl chlorid were fruitless.

The yield of crude light oil, compared to that of heavy oil, is small. Since the light oil differs but little from the heavy oil, it probably will be found expedient to collect and market or work it up along with the heavy oil in the operation of a commercial plant. One application to which this crude oil may be put is as a vehicle for cheap paints and shingle stains, and other such purposes for which certain of the creosote oils are now used.

HEAVY OIL.

The properties of the heavy oil which results chiefly from the destructive distillation of rosin resemble strongly those of rosin oil. The crude oil also contains decomposition products of the wood tissue, to which extent it is like wood creosote and rosin oil. The crude heavy oil is slightly heavier than water (average density of 1.048 at 20° C.), is brownish black, and has a penetrating, creosote-like odor. The average viscosity at 25° C. is 11.9° Engler. Like the light oil, it is comparatively unknown and untried, and therefore lacks a well-established market value.

Heavy oil is one of the important products obtained in the distillation of resinous woods. The yield is exceedingly variable, running from about 75 gallons a measured cord of very rich stumpwood to as little as 16 gallons from dead, down wood. Making up a large proportion of the total volume of oil recovered, its disposal to the best advantage possible is essential to the profitable operation of a commercial plant where the process is similar to that employed in this investigation. Consequently, certain experiments, looking to the most probable means by which an enhancement in the value of the crude oil may be expected, were conducted.

From the results of laboratory work it was found that in separating its low-boiling fraction by distilling at atmospheric pressure from a flask fitted with a Hempel column, distillation begins at an uncertain initial temperature of about 85° or 90° C., with an average recovery of 25 per cent (8.7 gallons a cord) below 225° C. This fraction is quite similar to the corresponding fraction obtained from the crude light oil.

The crude heavy oil can be used with some success for flotation purposes. In other fields of industry it must be sold largely in competition with products commonly obtained from coal tars such as

are used in the manufacture of roofing cement and shingle stains, and as a softener and binder in treating heavy cotton cloths with metallic resinates, for water and mildew proofing purposes. In Russia a similar pine product is used extensively as a leather dressing for harnesses, boots, etc. Either by itself or mixed with tar it might be successfully employed in the preparation of cordage, tar soap, moth-proof paper bags, leather dressings, etc. Bacteriological tests have shown it to possess a phenol coefficient equal to one-half that of carbolic acid.

Both the light and heavy crude oils, as well as some of the other products of this investigation, were examined to determine their adaptability to flotation purposes by the United States Bureau of Mines at Salt Lake City, Utah (page 54), and also by several mining companies operating in the western States. One company reported that while all the pine oils were generally satisfactory for zinc ores, the crude light oil and a partially refined pine oil were particularly good. Another stated that the results differed only slightly from those obtained with oil from the southeastern pines, this being one of the most effective oils for flotation purposes. Probably all would be good for copper ores if used in conjunction with kerosene sludge acid.

PITCH.

The average yields of pitch from all classes of wood are not widely different except those from dead, down wood, which are much smaller than those from richer woods. No tests, either physical or chemical, have been developed with which to compare the qualities of the different samples of resinous-wood pitch found in commerce, other than the presence or absence of foreign matter, and no specifications on the basis of which to make such comparisons have been established. For this reason, and because its most important application is for impregnating fibers in the manufacture of oakum and cordage, and for closing seams in the decks of vessels, when it is combined in various proportions with tar and turpentine to secure the consistency desired, a systematic examination of individual samples of this material has not been made. These differ so little, the only apparent distinction that could be drawn between samples being a slight variation in their relative hardness, that a general description will suffice.

The pitch is a black, brittle to slightly pliant solid, having a specific gravity of 1.144 to 1.148 and in hardness varying from that of common rosin, in the more brittle, to that holding a finger print and possessing slight tackiness in the softer samples at ordinary temperatures. So susceptible is it to temperature changes that samples which were found to be tough or pliant through the day became quite brittle during the night. Its melting point is consequently very indefinite. It behaves like a viscous fluid at 75° to 100° C., is sirupy

at 100° to 125° C., and free flowing at about 125° to 150° C. It is practically devoid of taste or odor, and dissolves readily in turpentine, but only very sparingly in either cold or hot alcohol, differing in this respect from common or black rosin. Its acid value was found to be 2, extracted with alcohol, against 150 to 180 for black rosin.

It differs from what is purchased under Government contracts for "North Carolina pitch" in being, on the whole, blacker, and somewhat softer, and in having, therefore, a generally lower melting point. It is believed, however, that this will not detract from its value in the uses previously enumerated, but rather that its somewhat greater pliability may be found to be advantageous.

CHARCOAL.

The charcoal obtained in these experiments from western yellow pine, especially that from the richer or more resinous samples of wood, is very soft and friable It retains an appreciable amount of bituminous matter, due undoubtedly to incomplete distillation, which causes it to burn with a long, smoky flame. Its possible application is suggested in industries where powdered fuel is used, or in metallurgical operations in which the crushing strength is not a prime requisite.

The charcoal from "bull" pine was in every respect superior to that obtained from yellow pine proper, and, in general, the quality of the charcoal fell off as the rosin content of the wood increased. Compared to that from hardwood, the western yellow-pine charcoal must be considered of inferior quality, especially as to hardness.

Tamarack charcoal has a much denser structure and is not so friable as that obtained from yellow pine. Moreover, it is clean or free from bituminous matter, and appears to be quite similar to hardwood charcoal.

ACID LIQUOR (PYROLIGNEOUS ACID).

The specimen log of a run (page 27) shows that an aqueous distillate which is nearly pure water comes over with the turpentine at the beginning of a distillation and is rejected. As the heating is continued, the wood tissue begins to decompose and the aqueous liquor takes on a straw color. From this point it contains acids and alcohol in varying quantities, and constitutes a true acid liquor, which in these experiments was retained and examined.

The acid liquor results from chemical transformations of bodies making up the wood tissue and rosin contained in the wood, brought about by heating the wood to a sufficiently high temperature. This reaction is a true chemical process, none of the compounds found in the liquor occurring in the untreated wood. The action is altogether different, therefore, from the recovery of turpentine and pine oils, the separation of which is effected by a physical change of

state. In other words, the heat serves only to convert these oils into vapors, which, after being cooled in the condenser, are collected essentially as originally present in the wood.

The three important constituents of acid liquor are acetic acid, methyl (wood) alcohol, and acetone. Up to the present time these products have been obtained almost exclusively from hardwood. Owing to the greater amount of tarry substances present, softwood acid liquor is extremely difficult to free from this constituent, and the calcium acetate made therefrom is inferior in quality to that from hardwood acid liquor. The yield, consisting of methyl alcohol and acetone, is also substantially lower than that from hardwoods.

The proportions of acid, alcohol, and acetone as found in these western yellow-pine acid liquors (Table 17) were obtained by analyzing a composite sample of acid liquor from each set of charges run on the various kinds of wood.[6]

TABLE 17.—*Composition of acid liquors.*

Grade and source.	Acid liquor, per cord.	Acetic acid.		80 per cent acetate of lime (calc. from acetic acid), per cord.	Methyl alcohol.		Acetone.		Dissolved oils and tars.	
		Per liter.	Per cord.		Per liter.	Per cord.	Per liter.	Per cord.	Per liter.	Per cord.
	Galls.	*Gms.*	*Lbs.*	*Lbs.*	*Galls.*	*Galls.*	*Gms.*	*Galls.*	*Gms.*	*Lbs.*
Poor stumpwood, Deary	59.4	67.76	33.6	55.3	27.82	2.10	2.24	0.20	.....	.....
Rich stumpwood, Deary	55.9	64.67	30.2	49.7	25.45	1.80	2.77	.16	120.08	56.0
Medium stumpwood, Deary	54.3	67.82	30.7	50.5	26.11	1.79	2.44	.16	134.58	60.9
Dead, down wood, Deary	53.4	64.49	28.7	47.2	25.98	1.76	2.33	.15	156.86	69.9
Rich stumpwood, Coeur d'Alene	60.9	64.37	32.7	53.8	23.19	1.79	2.00	.15	122.34	62.2
Medium stumpwood, Hayden Lake	61.4	65.44	33.5	55.1	27.35	2.13	1.92	.15	136.11	69.7
Bull-pine stumpwood, Boise	64.3	77.55	41.6	68.5	29.37	2.40	2.21	.18	172.12	92.3
Medium stumpwood, Boise	63.9	64.67	34.5	56.8	25.21	2.04	2.12	.17	133.90	71.4
Rich stumpwood, Boise	59.5	68.12	33.8	55.6	25.34	1.91	2.16	.16	128.54	63.8
Green selected stumpwood, Boise	63.6	71.05	37.7	62.0	27.64	2.23	2.42	.19	161.16	85.5
Green selected stumpwood, Craig Mountain	69.2	70.40	40.7	67.0	26.18	2.29	2.26	.19	159.29	92.0
Rich cut-over stumpwood, Craig Mountain	62.4	73.41	38.2	62.9	30.17	2.38	1.81	.14	152.37	79.3
Rich cut-over stumpwood, roadside, Craig Mountain	63.6	65.12	34.6	56.9	29.27	2.36	2.07	.16	143.31	76.0
Tamarack stumpwood, Moscow Mountain	74.0	41.95	25.9	42.6	13.88	1.30	1.49	.14	66.15	40.8
Selected dead, down wood, Craig Mountain	75.8	48.35	30.6	50.4	24.32	2.34	1.75	.17	119.71	75.7
Selected dead tops, Craig Mountain	63.2	57.90	30.5	50.2	27.71	2.22	2.09	.16	117.81	62.1
Selected green tops and limbs, Craig Mountain	80.8	49.67	33.5	55.1	28.09	2.87	1.73	.17	78.98	53.2
Medium stumpwood, roadside, Craig Mountain	66.6	58.21	32.4	53.3	28.21	2.38	2.10	.17	114.49	63.6
Rich stumpwood, near Potlatch	65.7	59.72	32.7	53.8	18.26	1.54	1.69	.14	120.83	66.1

[6] The analyses of the acid liquors were made by V. E. Grotlisch and G. C. Spencer, Bureau of Chemistry, United States Department of Agriculture.

The yield of calcium acetate is approximately but one-fourth of that generally obtained in distilling the best hardwoods. Probably on a commercial scale the yields would be somewhat less than those shown by the analyses. The yield of wood alcohol also is but one-fourth of that generally obtained in hardwood distillation.

PRODUCTS OBTAINED IN REFINING CRUDE TURPENTINE.

REFINED TURPENTINE.

In order to separate the valuable turpentine constituents of the crude turpentines from the pyroligneous and resinous heat-decomposition products of the wood, the crude turpentines are first treated with caustic soda, which combines with acids and resinifies the aldehydes and phenols, forming nonvolatile compounds. By a subsequent steam distillation the turpentine and pine oil are recovered. Just as in the case of the original retort distillation of the wood, the oily products of the steam distillation are separated into several fractions. The first product is called "first grade" or "first-quality refined turpentine." The receivers are changed at a certain point (page 58), and the distillate which then comes over is called "refined second-quality turpentine." This has distilling temperature limits somewhat higher than those accepted for true commercial wood turpentine. Finally, the receivers are changed again, the last of the distillate being called "pine-oil fraction."

On refining crude first turpentine a yield of approximately 80 per cent of refined first-grade turpentine is obtained, most of which distils between 170° and 175° C. From crude second turpentine the yield of refined first-quality turpentine lies in the neighborhood of 43 per cent. The other distillates from the crude turpentines are as follows: From crude first turpentine, 5½ per cent refined second-quality turpentine fraction and 7½ per cent pine-oil fraction; from crude second turpentine, 13 per cent refined second turpentine and 12 per cent pine-oil fraction.

TABLE 18.—*Properties of refined turpentine.*

Kind and source of wood.	Source.	Specific gravity, 20° C.	Refractive index, 20° C.	Color.	Odor.	Initial boiling point.	Amount distilling— Below 170° C.	Between 170° and 175° C.	Between 175° and 180° C.	Between 180° and 185° C.	Total below 175° C.	Total below 185° C.
	Crude.					*° C.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Rich stump, Viola	First	0.862	1.4728	Water white	Sweet	168.5	8.25	76.50	8.35	2.15	84.75	95.25
Do	Second	.864	1.4733	do	Good	167.3	7.95	63.20	19.35	4.35	71.15	94.85
Rich stump, Priest River	First	.861	1.4728	do	Sweet	169.0	2.50	81.95	8.60	1.95	84.45	95.00
Do	Second	.865	1.4730	do	Sweet; slightly disagreeable.	166.0	8.55	66.10	17.15	3.70	74.65	95.50
Dead, down limbs, Viola	First	.864	1.4726	do	Sweet	168.5			6.25	2.00	88.15	96.40
Do	Second	.866	1.4725	Nearly white	Peculiar; sweet	166.0	32.00	41.50	13.75	4.75	73.50	92.00
Fire-scarred butt, Viola	First	.864	1.4727	White	Sweet	168.0			7.75	2.50	85.75	96.00
Do	Second		1.4730	Pale green	Sharp; destructive.							
Poor stumpwood, Deary	First	.860	1.4729	White	Sweet	169.0			9.50	2.50	80.75	92.75
Do	Second	.867	1.4732	Faint yellow	do	166.0	14.65	58.00	15.35	4.65	72.65	92.65
Rich stumpwood, Deary	First	.860	1.4722	White	do	168.5			7.00	2.00	86.75	95.75
Do	Second	.863	1.4728	Faint yellow	do	168.0	8.33	63.66	18.33	4.33	72.00	94.65
Medium stumpwood, Deary	First	.861	1.4729	White	do	168.0	19.50	67.00	7.25	1.75	86.50	95.50
Do	Second	.864	1.4730	Faint yellow	do	167.0	15.33	53.33	17.00	5.00	68.66	90.66
Dead, down limbs, knots, Deary	First	.860	1.4723	White	do	168.0	13.50	71.50	8.00	2.00	85.00	95.00
Do	Second	.865	1.4725	Faint yellow	do	168.0	9.33	63.33	16.66	4.33	72.66	93.65
Rich stumpwood, Coeur d'Alene	First	.861	1.4722	White	do	168.0	21.00	65.25	6.00	2.25	86.25	94.50
Do	Second	.864	1.4727	Faint yellow	do	167.0	11.00	63.33	16.33	4.00	74.33	94.66
Medium stumpwood, Hayden Lake.	First	.863	1.4727	White	do	169.0	7.00	79.25	8.25	2.25	86.25	96.75
Do	Second	.865	1.4732	Faint yellow	do	168.5	9.33	65.33	17.33	3.66	74.66	95.65
Bull-pine stump, Boise	1st & 2d	.865	1.4708	Faint yellow	Disagreeable	165.0	59.33	30.00		6.00	89.33	95.33
Medium stumpwood, Boise	First	.860	1.4722	White	Sweet	169.5	4.50	81.25	7.25	1.75	85.75	94.75
Do	Second	.865	1.4730	Faint yellow	do	168.0	7.50	68.00	14.75	4.00	75.50	94.25
Rich stumpwood, Boise	First	.860	1.4724	White	do	168.5	19.75	63.25	7.75	2.00	83.00	92.75
Do	Second	.864	1.4725	Faint yellow	do	168.0	10.00	63.75	15.50	4.50	73.75	93.75
Selected green stump, Boise	First	.861	1.4723	White	do	168.0	17.50	68.50	6.00	1.50	86.00	93.50
Do	Second	.865	1.4729	Faint yellow	Peculiar; sweet	167.5	13.25	67.50	11.25	3.00	80.75	95.00
Selected green stump, Craig Mountain.	First	.862	1.4726	White	Ethereal; sweet	169.0	13.00	72.50	7.00	1.50	85.50	94.00
Do	Second	.865	1.4728	Faint yellow	Sweet	168.5	10.00	65.25	14.50	3.50	75.25	93.25
Roadside rich stumpwood, Craig Mountain.	First	.862	1.4726	White	do	168.5	9.50	71.00	10.00	2.75	80.50	93.25
Do	Second	.865	1.4730	Faint yellow	do	165.0	14.00	56.00	14.66	5.33	70.00	89.99
Roadside medium stumps, Craig Mountain.	First	.861	1.4722									
Do	Second	.862	1.4725									

Rich cut-over stumpwood, Craig Mountain.	First	.860	1.4726	White	Sweet	170.0		83.75	8.75	2.00	83.75	94.50
Do	Second	.864	1.4726	Faint yellow	do	168.5	9.00	60.33	19.33	4.66	69.33	93.32
Selected dead, down knots, etc., Craig Mountain.	First	.858	1.4722									
Do	Second	.861	1.4723									
Selected dead tops, Craig Mountain.	First	.859	1.4730									
Do	Second	.861	1.4730									
Selected green tops, limbs, etc., Craig Mountain.	First	.858	1.4725									
Do	Second	.861	1.4728									
Tamarack stump, Moscow [1]												
Large, rich stumps, Potlatch	First	.859	1.4725									
Do	Second	.862	1.4730									
Heartwood, small stumps, Potlatch.	First	.856	1.4722									
Do	Second	.860	1.4728									

[1] None.

PINE OIL.

Pine woods contain oils other than those entering into the composition of commercial spirits of turpentine. These oils, collectively spoken of as pine oil, are liberated more or less completely from the wood in their original form, along with the turpentine constituents proper. This pine oil is a complex substance made up to a large extent of oxygenated derivatives of the terpenes (turpentine constituents), and has a comparatively high boiling point and specific gravity. The characteristic odor of pine wood is due chiefly to the presence of this oil, in conjunction with turpentine. The characteristic odor of wood turpentine is also due to small quantities of pine oil present. The quantity of this oil recovered is always relatively small, varying from a total of $3\frac{1}{3}$ gallons from a cord of very rich stumpwood to less than 1 gallon from a cord of dead, down wood and poor stumps. It is necessary to remove or separate this oil as completely as possible from the turpentine, because it does not evaporate readily, and a turpentine containing even a small percentage of it will remain sticky or "tacky" after drying. Its value as a thinner in the paint and varnish industry would be affected accordingly.

The sum of the total refined turpentine and pine oil recovered from the crude first turpentine amounts, on an average, to 92 per cent, and that from the crude second turpentines to 70 per cent. On the basis of the average yields from rich and medium stumpwood, this would amount to 13.5 and 7.8 gallons a cord for the first crude turpentine, and 8.3 and 5.7 gallons for the second crude turpentine. These are the results obtained when the steam distillation is continued to the point where the oil layer makes up 5 per cent of the total distillate coming over at the time. By continuing the distillation to exhaustion, or until no more oil is carried over by the steam, an additional 5 or 8 per cent of pine oil may be recovered. Considerations for economy of operation did not warrant the carrying of the distillation to this state of completion. The composition of the pine oil progressively changes, so that the portion coming over at the close of the distillation is heavier than that passing over at the earlier stages.

ALKALI RESIDUUM.

On prolonged standing the black, alkaline liquid remaining from the distillation separates into an aqueous layer and a thick, oleaginous, soaplike mass which floats on top of the water. This mass will be designated " alkali residuum." Dissolved in the aqueous layer is a small proportion of what appears to be creosote bodies. The alkali residuum, which is essentially an impure rosin soap, dissolves in water to form a colloidal solution of great stability that exhibits

an alkaline reaction. This solution possesses germicidal properties, the undiluted material having a phenol coefficient of 0.5. When the alkali residuum is decomposed by the addition of acid in excess, a heavy oil separates, about 75 per cent of which distils over between 180° and 340° C. Most of this distils between 200° and 300° C. The higher-boiling portion has the general appearance and odor of rosin oil. When the alkali residuum is distilled without previous treatment with acid, about 3 per cent of its volume is recovered as pine oil, along with 30 per cent of water, after which the residue remaining in the flask solidifies to a hard, soaplike mass soluble in water, forming a colloidal solution similar to that from the original alkali residuum.

CALCULATION OF YIELDS OF REFINED TURPENTINE AND PINE OIL.

A composite sample of the refined second-grade turpentine when dry distilled through a fractionating column yielded 83 per cent of turpentine distilling between 170° and 185° C., having a density of 0.8622 and a refractive index of 1.4736. The residue from this distillation was a true pine oil, the density of which was 0.9423, with a refractive index of 1.4937. A composite sample of the pine-oil fractions obtained in refining first and second crude turpentines, distilled in a like manner, gave 40 per cent of turpentine distilling between 175° and 185° C., the density and refractive index of which were 0.8655 and 1.4755, respectively. The residuum was also true pine oil similar to that remaining from the distillation of the second-quality turpentine.

The properties of the turpentine fractions thus obtained from the refined second turpentine and the pine-oil fractions do not differ markedly from those of the refined first turpentine. Moreover, the volume being but small compared to that of the refined first turpentine, it is believed that these may be combined without materially lowering the quality of the product. The total merchantable turpentine, therefore, will be figured on the basis of the first refined turpentine plus 83 per cent of the corresponding second refined turpentine and 40 per cent of the pine-oil fraction, respectively. The sum of the three is entered in the " merchantable turpentine " column of Table 14.

On the same basis, the volume of true pine oil will be 17 per cent of the refined second turpentine plus 60 per cent of the pine-oil fractions obtained in refining the crude turpentines. The yield of pine oil given in the " merchantable pine oil " column of Table 14 is thus obtained. The sum of the refined first and second turpentine and pine-oil fraction is not equal to the sum of the first and second crude turpentine. The portion thus unaccounted for is retained dur-

ing the refining process, partly in the alkali residuum and partly in the aqueous distillate.

A summary of yields a cord of both crude and refined products obtained from each class of wood is given in Table 19.

TABLE 19.—*Yields per cord of crude and refined products from each class of wood distilled.*

Product.	Rich stumpwood (8 samples).			Medium stumpwood (6 samples).			Green stumpwood (2 samples).			Dead, down wood (4 samples).			Poor stumpwood (1 sample).	Green tops and limbs (1 sample).
	Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.		
Crude first turpentine (A) ..... gallons..	17.1	13.3	14.9	12.1	6.8	9.0	9.9	8.7	9.3	17.8	4.5	8.6	6.9	3.1
Crude second turpentine (B) ..... gallons..	17.8	7.6	11.1	10.5	6.4	8.1	7.4	5.0	6.2	13.5	2.8	6.3	6.8	2.8
Total ..... do....	34.9	21.0	26.0	22.6	13.5	17.1	16.1	14.9	15.5	31.3	7.3	14.9	13.7	5.9
Crude light oil ..... do....	8.3	2.7	4.6	4.9	2.8	3.6	3.2	2.5	2.9	4.9	2.8	3.6	2.9	3.3
Crude heavy oil ..... do....	70.5	29.5	46.0	31.7	24.4	26.5	32.1	30.1	31.1	47.0	19.5	28.6	23.6	16.1
Acid liquor ..... do....	74.4	55.9	64.4	74.4	54.3	64.1	69.2	63.6	66.4	75.8	53.4	63.6	59.4	80.8
Refined first turpentine from A ..... gallons..	13.3	10.0	11.8	9.7	5.1	7.1	8.1	7.2	7.6	13.6	2.6	6.4	5.7	2.0
Refined first turpentine from B ..... gallons..	7.9	3.1	5.0	6.1	1.5	3.6	3.8	2.5	3.2	2.9	.8	1.8	2.8	1.1
Total ..... do....	21.2	13.4	16.8	15.8	6.6	10.7	11.0	10.6	10.8	16.5	3.4	8.2	8.5	3.1
Refined second turpentine from A ..... gallons..	1.3	.6	.8	.8	.4	.6	.7	.4	.5	1.3	.3	.7	.4	.3
Refined second turpentine from B ..... gallons..	2.3	.9	1.5	1.5	.9	1.1	1.0	.5	.8	1.9	.3	.8	.7	.3
Total ..... do....	3.0	1.7	2.3	1.9	1.3	1.7	1.4	1.2	1.3	3.2	.6	1.5	1.1	.6
Pine oil fraction from A ..... gallons..	1.7	.9	1.2	1.1	.3	.7	.5	.3	.4	1.6	.3	.7	.3	.2
Pine oil fraction from B ..... gallons..	2.6	1.1	1.5	1.2	.9	1.0	.5	.4	.5	2.8	.3	1.1	.6	.3
Total ..... do....	4.3	2.2	2.7	2.1	1.2	1.7	.9	.8	.9	4.4	.6	1.8	.9	.5
Merchantable turpentine ..... gallons..	25.7	16.2	19.8	18.0	8.9	12.7	12.5	11.8	12.2	21.0	4.6	10.2	9.7	3.8
Merchantable pine oil ..... gallons..	3.1	1.6	2.0	1.6	1.0	1.3	.8	.8	.8	3.1	.4	1.3	.8	.4
Pitch ..... pounds..	237	110	188	188	102	131	144	143	143	104	42	84	83	22
Charcoal ..... do....	988	670	789	800	651	711	823	768	795	863	671	790	714	764
Cord weights ..... do....	3,500	2,500	2,812	3,000	2,200	2,417	2,500	2,400	2,450	3,000	2,000	2,400	2,100	2,400

The average weight a cord of the rich stumpwood is 2,612 pounds, as against 2,450 pounds for selected stumpwood, and 2,412, 2,400, 2,100, and 2,400 pounds for medium stumpwood, dead, down knots and limbs, poor stumpwood, and green tops and limbs, respectively. The corresponding yields of refined first turpentine are 16.8, 10.8, 10.7, 8.2, 8.5, and 3.1 gallons a cord; and the yields of total merchantable turpentine are 19.8, 12.2, 12.7, 10.2, 9.7, and 3.8 gallons a cord, respectively. With the exception of that from the green tops and limbs, the yield of turpentine a cord follows the weight a cord. The yields of pine oil and crude light oil, while not varying greatly,

show the same tendency to follow the weight a cord and field classification of the wood. This tendency is shown also by the yield of heavy crude oil and of pitch. The acid liquor and charcoal, however, are not subject to any such general deductions, although the highest yields of acid liquor are generally given by the green woods, followed by the richer stumpwood. In all probability this is due to the fact that acetic acid is one of the decomposition products of rosin.

An experienced person can classify stumps in the field into several grades from which the average yields of valuable products differ to such an extent as to necessitate a proper selection of the material before collection.

COMMERCIAL DISTILLATION PROCESSES.

There are four general processes for the recovery of products from resinous wood. Two of these are destructive distillation processes and two are nondestructive extraction processes. They are: (*a*) The common or ordinary destructive distillation process; (*b*) the controlled temperature destructive process; (*c*) the steam distillation or extraction process; and (*d*) the solvent extraction process. Of these the ordinary destructive distillation process is the only one which seems to be well adapted to the stump-disposal project in the Northwest.

ORDINARY DISTILLATION PROCESS.

The wood-distilling oven now in general use for the destructive distillation of wood is an outgrowth of the old charcoal heap. By-product charcoal kilns, round iron retorts, and rectangular iron or concrete ovens are in use, the rectangular oven being preferred in the best practice. Experience with these different forms has taught that there is a mean temperature which gives the most satisfactory yields. This temperature is necessarily more difficult to maintain in direct-heated retorts, the smaller of which have the further disadvantage that the charcoal must be removed by hand, necessitating a loss in time required for cooling as well as a fuel loss in reheating the retort for the next charge.

The uneconomical working of the round retort has led to the development of the rectangular oven. Such ovens are of steel or concrete construction and are heated either directly by fires under them, in the case of the steel ovens, or by means of internal-heating flues in the concrete ovens. The second method is said to be better adapted to softwood distillation. The height and width of the ovens are uniform, being in general 8 feet 4 inches and 6 feet 3 inches, respectively, and the length ranges from 26 to 54 feet or more, accord-

ing to the desired capacity. An oven 52 feet long, 6 feet 3 inches wide, and 8 feet 4 inches high holds 10 cords of wood.

The charge of wood, of regular cordwood size, is loaded onto steel tramcars of special construction and hauled into the retort or oven, which is, of course, tightly closed during the distillation. At the end of this operation, the train of cars bearing the still hot charcoal is hauled out into the cooling shed of sheet iron, where the charcoal cools down without loss of fire. Simultaneously, another trainload of wood enters the oven, and the new distillation proceeds with a minimum heat loss.

In addition to the ovens, coolers, cars, and necessary brickwork or the setting of the ovens, condensers, which should be of ample capacity to handle the distillate under the most unfavorable operating conditions, will be required, as well as stills, steel tanks to hold the product, wooden tanks, pumps, generators, steam boilers and engine, yard tracks, piping, etc., and the necessary buildings for housing the plant.

A conservative estimate of the cost of such a plant is between $4,000 and $5,000 a cord capacity. Before the war these plants could be built for from $1,500 to $3,000 a cord capacity, or at a total cost, including working capital, of approximately $20,000 for a 10-cord plant. The cost of construction and of operation and the design and character of the equipment will vary, and quite widely, with the proposed location of the plant and the work it is to do, and with the experience and practice of the designing and constructing engineers. For these reasons, no details of equipment or specifications are given. This information can best be secured from wood-distillation engineers and from builders of the equipment, whose advertisements appear in the various industrial journals. The Bureau of Chemistry can furnish a list of engineers and builders of wood-distilling plants.

CONTROLLED TEMPERATURE PROCESS.

The controlled temperature or circulating oil process and retort have been fully described in the preceding pages. Even on a commercial scale a prerequisite of this process is that the pieces of wood be relatively smaller in diameter than those used in the ordinary destructive process, to insure rapid distillation. When properly carried out, better separation of the several products of distillation is obtained, with the result that the turpentine ordinarily obtained commands a slightly higher price (3 to 5 cents a gallon) for paint or varnish purposes than the turpentine produced by the regular destructive process, in which the temperature is not definitely controlled. While this process yields a better grade of wood turpentine, the equipment and upkeep are more expensive, and greater skill and

a larger force are required in operating than for the uncontrolled process. For this reason it is rarely used for distilling resinous wood.

STEAM DISTILLATION PROCESS.

The steam distillation process requires that the wood to be extracted shall be finely divided by chipping or shredding before treatment; the finer the chips, the more rapid and complete the extraction. For this reason the steam process has been installed by several sawmills for the recovery of turpentine from sawdust. The best results are not obtained with all dust, however, as it packs so tightly that the steam is kept from penetrating throughout the entire mass to be extracted. Chips of a size passing an inch and retained by a quarter-inch screen are desirable, and a limited amount of sawdust can be mixed with such chips.

Few plants, other than lumber mills where the production of wood turpentine and pine oil is only a side issue, have continued to operate on the steam process alone, and have invariably closed when turpentine sold at less than 50 cents a gallon. The turpentine produced by this method is of high quality, approaching that made by the regular distillation from gum. The practicability of maintaining a steam distillation plant depends entirely on market conditions; if the price of turpentine is sufficiently high the steam method will be a paying proposition. The steam distillation outfit is now usually installed in conjunction with a solvent plant that can extract the residual wood chips for the recovery of rosin and certain of the heavier pine oils.

SOLVENT EXTRACTION PROCESS.

In the solvent process also the wood must be finely divided. This process is one where the wood is extracted in large, tight digestors at a relatively high temperature by means of suitable volatile solvents, the choice of which is determined mainly by price. Gasoline, coal tar, naphtha, or turpentine can be used, gasoline being the one in common use. When the solvent is added in the beginning of the operation, that is, with no previous steam distillation, all of the soluble pine products are removed altogether, and the resulting mixture is fractionated to recover the naphtha or other solvent and to separate the turpentine and pine oils from the rosin. The rosin obtained in this way is not so free from tackiness as pure gum rosin, and has a rather darker color, but is quite clear when properly made. Furthermore, it is very difficult to remove the solvent completely from the turpentine. It has been found advantageous, therefore, to combine the steam and solvent processes, the only objection to this being that the steam leaves the chips in a moist condition, in which state the extraction does not take place as readily as if they were absolutely dry.

BATH PROCESS.

An advantage of the bath process, another method which has been used to a limited extent, is that the wood does not require previous shredding. The wood is run into the retort on cars, and the retort is flooded with a high-boiling material, such as molten rosin, pitch, or tar, heated to a sufficiently high temperature. Most of the extracted turpentine and pine oils are volatilized at the temperature of the bath, and the rest is blown out of the bath with steam. The remaining wood, which is saturated with the rosin or other material of the bath, may be destructively distilled to recover the light and heavy crude oils, tar, charcoal, and pitch.

FEASIBILITY OF DISTILLING WESTERN YELLOW PINE.

Yellow-pine stumps of a quality such as to yield more than 12½ gallons a cord, the average yield from medium-grade stumpwood, of merchantable wood turpentine, of the properties shown in Table 18, and other products in corresponding proportion, are comparatively scarce. "Fat" or "pitchy" stumps, averaging 20 gallons of merchantable turpentine a cord, are not sufficiently numerous to be considered in a class by themselves as an impediment to land-clearing operations, and would need to be hauled for long distances in supplying wood to distilling plants.

The daily yield from a 10-cord plant and the market value of the products from the rich portion of medium-grade stumps, based on the yields obtained in these experiments and on the prevailing eastern prices June, 1918, using the ordinary ovens in general use, would be approximately as follows:

Merchantable turpentine	127 gallons	@ $0.50	$63.50
Pine oil	13 do.	@ .40	5.20
Light oil (at tar oil prices)	35 do.	@ .20	7.00
Heavy oil (at tar prices)	275 do.	(6 barrels) @ $0.15	41.25
Pitch	7 barrels	(1,400 pounds) @ $3.50	24.50
Charcoal	350 bushels	(7,110 pounds) @ $0.12	42.00
			183.45
Total value of products a cord of selected medium-grade resinous wood or heartwood			$18.36

The average yield and market value of the products recovered from a cord of rich stumpwood on the same basis are estimated to be:

Merchantable turpentine	19.8 gallons	@ $0.50	$9.90
Pine oil	2.0 do.	@ .40	.80
Light oil	4.5 do.	@ .20	.90
Heavy oil	46.0 do.	@ .15	6.90
Pitch	138.0 pounds	@ 3.50 a barrel	2.41
Charcoal	38.0 bushels	(790.0 pounds) @ $0.12	4.56
Total value of products a cord			25.47

These yields and values are comparable to those obtained in distilling longleaf-pine lightwood in the South Atlantic States, as shown by the following figures, taken from Bureau of Chemistry Bulletin 144:

Products from 1 cord (4,000 pounds) of longleaf yellow-pine lightwood (destructive process).

Total crude oil	gallons	36 to 120
Refined wood turpentine	do	5 to 20
Pine oils	do	2 to 5
Rosin oil	do	20 to 65
Light and heavy oils:		
Creosote	gallons	8 to 20
Rosin spirits	do	2 to 10
Charcoal	bushels	30 to 50

Cost of operating per day and per cord (1915 figures).

10 cords of wood, at $8.37 a cord, delivered	$83.70
Fuel wood, in addition to gases and fine charcoal, 10 cords, at $2.50 a cord, delivered	25.00
Labor, 8 men (3 shifts), at $2.50 a day (average wage)	20.00
Technically trained works manager, at $125 a month	4.15
Depreciation, at 15 per cent of investment in plant ($20,000)	8.20
Upkeep, at 8 per cent of investment in plant ($20,000)	4.40
Insurance, at 3 per cent of investment in plant ($20,000) (average)	1.65
Chemicals for still house, etc	1.00
Barrels or other containers for making deliveries	15.00
Interest on total investment ($25,000), at 6 per cent	4.11
	167.21
Total daily production cost, exclusive of sales or marketing expenses, a cord	16.72

Marketing expenses, although an important item, are not included, because they depend largely on the business policy of the management and upon competition.

The cost of operating a plant in the South Atlantic States is but little more than half this estimate, because of the much lower cost of wood and of labor in the South. If the medium-grade wood could be distilled at the usual southern cost, it would yield a fair return. The approximate cost of operating a destructive distillation plant in the South Atlantic States is as follows:

Cost of wood for distilling, a cord	$1.50 to $3.00
Management, labor, fuel, packing, a cord	2.50 to 6.00
Interest and depreciation, a cord	.60 to 1.60
Total	4.60 to 10.60

The values assigned to the several products are representative of those prevailing on the eastern coast shortly after the European war started. To this must be added the cost of transportation to

the West and western dealers' profits, which were not included for the reason that they vary greatly, and also because local freight rates to interior points would, in many instances, be nearly as great from western points to consuming points as the through rates from the South to the same consuming points. Since, in any event, such competitive freight charges would vary greatly with the locality, they are not included in the estimation of values here given, but they must receive very careful consideration before the erection of a plant for the recovery of products from wood.

On the basis of the foregoing carefully considered and conservative estimates of cost of production and of the value of products, it must be concluded that stumps of medium quality, giving the average yields stated, can not be profitably utilized generally by the destructive distillation methods. Needless to state, if, because of exceptionally favorable local conditions, the cost of wood at the plant can be materially reduced, wood of medium richness could be profitably distilled. Such localities should be given very thoughtful and systematic consideration by experienced and practical distillation experts before undertaking their exploitation.

Since poor stumps and dead, down wood contain even less resinous matter than the medium stumps, they could not be profitably distilled.

On the other hand, the rich or pitchy stumps contain enough resins to make their distillation profitable in those localities where they are sufficiently numerous. With wood containing enough resinous matter to average the yields given for rich stumpwood, obtainable at even $10 a cord, a wide margin of profit is possible by the process outlined, provided all the products can be marketed at prices not materially lower than those used in the foregoing estimate. To maintain an adequate wood supply of this quality, sufficient for a plant to operate a number of years, it will be necessary to resort to a long-distance railroad haul and long-distance wagon transportation to railroad sidings. For this reason, a cost of something like $10 a cord should be allowed in estimates for such wood, the cost of getting out the stumps alone exceeding $6. The possibility of obtaining at reasonable prices sufficient quantities of rich stumps which are thinly distributed over the land, entailing a high cost of collecting, is the vital point in considering the practicability of wood distillation in the Pacific Northwest.

The impression that more material than that obtained from the rich stumps might be drawn on, because, the margin of profit for this material appearing quite large, an appreciable proportion of wood intermediate in quality between that from rich and that from medium-grade stumps combined with the rich grade would give a material worth working up, would in general be misleading.

When stumps of the different grades (p. 15) were dynamited but little difference was found between the poor and medium-quality stumps. Furthermore, unless the exudation of rosin is exceptionally abundant, it can not be taken as an indication that the stumps are rich or pitchy. So disappointing was this superficial indication of quality, used before its true value was established from dynamiting a number of stumps, that, to avoid shipping a lot of what was plainly worthless material, the poor stumps were taken from those that had been classified as medium, leaving only a few specially selected stumps from which the rich wood proper was obtained.

In view of these facts, poor and medium-quality stumps, as the terms are used in this bulletin, are those in which the sound heartwood approximately equals in resinous appearance that found in the heartwood of an average yellow-pine log, except that it is richer toward the spreading of the roots. The resinous material in such wood comes largely from this portion of the stump. Medium stumps differ from poor stumps only in that there is a somewhat larger proportion of the very resinous wood at the spreading of the roots, the main volume of heartwood in these two classes of stumps appearing to be essentially alike. Rich or pitchy stumps differ from the medium in that the heartwood is more uniformly resinous throughout the whole of the stump and constitutes perhaps from 60 to 80 per cent, or more, of the whole stump, while in the poor and medium stumps the resinous portion constitutes less than half of the entire stump.

To verify the conclusion that the rich or pitchy stumps average not more than a cord an acre of wood suitable for distillation, all the stumps on a typical area were removed, representative samples selected, and an estimate made of the total quantity of such wood on the area from which stumps were taken. This selected representative acre contained 12 stumps, 9 of which were classed as medium to poor, and 3 as resinous or rich. The 9 nonresinous stumps contained between 3 and 4 cords of wood, of which but 1,500 pounds, or one-half cord, was sound heartwood, the remainder being doaty, nonresinous sapwood, which was separated from the heartwood in the field, only the heartwood being taken to the laboratory. At least 80 per cent of worthless nonresinous material was split out of these stumps in obtaining the half cord of heartwood. In the large resinous stumps there were 1½ cords of resinous wood, all of the quality represented by the sample. The nonresinous stumps, though quite large (36 to 40 inches), were smaller than the resinous stumps.

The wood selected from that classed as the less resinous stumps was richer than that from the 3 rich stumps. Weight for weight of material in the selected samples this is true. However, of the wood running 18 gallons of turpentine a 3,000-pound cord, only about 1,500 pounds, or one-half cord, in the entire lot of 9 stumps contained an estimated volume of 3 or 4 cords of wood. To run all of this wood would eliminate the cost of splitting out the resinous wood from the sapwood. It would, however, quadruple the cost of rail and wagon haul and the time and cost of distilling, and, at the same time, would cut down the yield to about 5 gallons a cord of very inferior turpentine, with a proportional reduction in other products.

The half cord of resinous wood from the 9 stumps, combined with that from the 3 more resinous stumps, gave about 2 cords of wood, running 17 gallons of turpentine a cord. Had all the wood on the acre plot been used, there would have been 6 cords, yielding not more than 6 or 7 gallons of turpentine a cord, with the other products in like proportions. Neither the results of these experiments nor the wood-distillation practices in the South warrant the belief that wood of this quality can be profitably distilled. It is better to split out and reject the low-grade wood.

While a large proportion of the yellow-pine stumps in Idaho contain a certain amount of resinous wood which is as rich as the truly pitchy stump, such wood forms so small a proportion of the entire stump that its removal from the nonresinous wood is prohibitively expensive. The case is similar to that of many ore-bearing formations in which the valuable mineral is disseminated through so large a proportion of worthless material as to make its concentration in a form rich enough for treatment commercially impracticable.

At the 1915 prices for raw material and for products, wood from 60 to 80 per cent of which must be split off and rejected, or wood which will yield but 6 gallons of turpentine or a total of 30 gallons of resinous products a cord, could not be profitably distilled. When the nonresinous portion of the stumps has rotted away, leaving only the resinous heart, this material, which then would be similar to the rich stumps, could, of course, be profitably used, provided the ratio of cost to selling value remained essentially the same.

Future careful studies of the uses to which the heavy crude oil may be put probably will result in a revision of the price here assigned to it. That of 15 cents a gallon is based on its probable value for uses to which certain of the creosote oils are being put. Undoubtedly its value can be enhanced by suitable refining methods, or by working it up into special products. These would necessitate additional equipment and labor, thus increasing the manufacturing cost, the probable expediency of which can not be foretold. The same con-

sideration applies to the light-oil fraction. From the prevailing price of articles with which such refined or special products must compete, it is doubtful if the balance between production cost and market value of the output of a plant would be materially affected thereby.

The acetone, wood alcohol, and acetic acid content of the aqueous distillate is, roughly, one-fourth that obtained in the crude distillate from hardwood plants. The value a cord of the alcohol and acetic acid recovered as acetate of lime, based on 1915 prices, is approximately $1 and $1.50, respectively. The crude liquor as obtained from the retorts is so heavily charged with tarry bodies that the acetate if obtained therefrom by the ordinary method is of a low grade and at best usually commands too low a figure to make its recovery profitable. Even by some improved processes, the recovery of these three products, which would increase the gross income by about $2.50 a cord, could be accomplished at best only on a narrow margin of profit, and the earning power of a plant thus equipped would not be materially increased by so doing. A company in the Northwest, operating a wood-distilling plant on selected Douglas fir mill-waste, including the recovery of these products in their margin of profits, found the enterprise, as then carried out, unprofitable.

One other possibility needs to be mentioned. It has been stated that lean and also medium resinous stumps contain small proportions of heartwood nearly if not quite as rich in resin as the resinous portions of rich stumps, but the proportion of such wood is so small that the cost of splitting it out would be prohibitive. Should the nonresinous portion rot off the lean and medium stumps in the course of a few years, as happens in the longleaf yellow-pine cutover lands, the remainder or heart of the stump would then be practically 100 per cent resinous and suitable for distillation. Unfortunately, few such rotted stumps showing only the sound, rich heart were observed in any of the districts visited. The rotting off of the sapwood would unquestionably proceed more rapidly farther south.

RELATION OF WOOD DISTILLATION TO LAND CLEARING.

One of the purposes of this investigation was to secure information on what part of the cost of clearing land for farm purposes might be paid for by distilling the wood or by selling the wood for distillation.

The cost of clearing land for farming in the Pacific Northwest varies widely, depending on the size, number, and age of the stumps, the lay, nature, and water content of the soil, cost of labor and materials, and other factors. The United States Department of Agriculture, in cooperation with the State agricultural experiment stations of Washington, Wisconsin, and Minnesota (11), and the Uni-

versity of Idaho (8), have done much actual work on land clearing in this section, and have found the cost of clearing for farm purposes to vary from $50 for the lightest clearing ground to $150 an acre for heavily wooded hardwood land.

In the sections from which samples were collected 20 yellow-pine stumps to the acre is a high average on land where the stand is mostly or entirely yellow pine; under more commonly occurring conditions in which there is more of a mixed stand, such as in the Potlatch-Deary district, 10 to 12 yellow-pine stumps to the acre is more nearly correct.

If, as indicated by these investigations, 10 per cent of the yellow-pine stumps are of the rich, resinous type, yielding 20 gallons of turpentine and other products in proportion a cord, or 15.4 gallons a ton, the 12 stumps an acre would yield 1 cord, and 20 stumps about 2 cords of wood an acre.

If the wood could be disposed of for $10 a cord, the return for the extra labor, time, and expense required to split and sort out the resinous wood and haul it to a shipping point would be from $10 to $20. Experiments in clearing 1 acre carrying 12 yellow-pine stumps, varying from 2 to 5 feet in diameter (page 18), have shown that this return will a little more than pay for the powder needed to blast out all the yellow-pine stumps. In other words, provided a market for the wood at $10 a cord is available, the net cost of land may be reduced from 6½ to 40 per cent, less the cost of sorting and hauling to a shipping point.

The chief question is whether a farmer can afford to shoot all the yellow pine clear of the ground, or crack with explosives and pull the pieces with a puller, then sort the wood and haul it to the railroad, or whether he can get his land cleared more cheaply by using some of the methods of burning described in Idaho Agricultural Experiment Station Bulletin 91, or United States Department of Agriculture Farmers' Bulletin 974. If the returns from the fat stumps on a tract are sufficient to justify the more expensive methods of clearing, and it is some advantage to have all the roots out of the ground, blasting is the method which will be most used.

About 100 pounds of explosive would be required to shoot clear of the ground all the yellow-pine stumps on an acre, while 25 pounds would crack them enough so that they could be burned. In the first case, the cost of explosive (1914–15) would be about $15 and in the second case $4. The explosive could be placed with a little less work if the stumps were to be burned. Possibly it would require about the same amount of labor to burn the stumps in the ground as it would to sort over the pieces, burn those unfit for distillation purposes, and haul the rest to the railroad. On the assumption that it would, it

will be seen that the farmer would just about break even if he could sell the rich wood for $11 an acre.

A wood-distilling plant of any size can not operate profitably without an ample and steady supply of rich wood extending over a number of years. For this reason a wood-distilling plant should be built and conducted as an independent business rather than primarily as a means of meeting the cost of land clearing. Naturally, it would be located with reference to available material; that is, where there was land ready to be cleared. Such wood as the settlers could supply would be simply an addition to the stock, though in some instances the bulk of the wood might be obtained from this source.

In the Winchester and Craig Mountain country, where the conditions are quite different from those observed in the other sections, there is a close almost pure stand of yellow pine. As there are no heavy underbrush or slashings, clearing such cut-over lands consists practically entirely in burning the tops of the cut trees and removing about 20 large yellow-pine stumps.

The comparative absence of younger growth between the trees, fairly even surface of the country, and uniform stands, of which perhaps 40 per cent of the stumps are quite rich or resinous, make such sections possible localities in which the cost of land clearing may be met, in a large part at least, if not entirely, by distilling the stumps.

SMALL, SEMIPORTABLE WOOD-DISTILLING PLANTS.

Wood-distilling plants as usually constructed where the daily capacity varies from 10 to 100 cords of wood, are permanent, especially when a number of products are made and refined for market. Furthermore, such plants require capital for financing and technical skill and experience for profitable operation. Therefore, wood-distilling plants would be comparatively few, and small plants of about 1-cord capacity that can be set up, torn down, and relocated at will would be useful, particularly in sections removed from railroads and where transportation is difficult. Especially would this be true if the mixed crude oil and tar obtained could be profitably disposed of to refiners or directly to users.

Since the work described in this publication was completed, private companies have built and operated such small plants. Plants of this kind, of 1-cord capacity, can be built for from $3,500 to $4,500. They might be bought and operated by a community, the crude oil being sold direct to the zinc, lead, and copper miners, who use it for the concentration of ores by the flotation process. The cheap, semiportable 1-cord retort is probably better adapted to Northwest conditions than are the large, more permanent, and more expensive plants making and refining a number of products.

USE OF OIL FOR ORE FLOTATION.

Of the many oils that have come into use for ore flotation, oil of eucalyptus, costing about $1.50 a gallon, is prized most highly. Next in the order of merit come the pine oils, selling for from 40 to 60 cents a gallon. In the effort to discover cheaper oils, most of the wood creosotes, as well as many coal-tar creosotes, have been found to be acceptable. They range in price from 15 to 30 cents a gallon. Producers of petroleum have also entered the flotation field, though with but limited success when petroleum alone is used. Better results are obtained by mixing a small amount of pine or creosote oil with the crude petroleum. "Kerosene sludge acid" from California oils, obtained by treating the crude oil with sulphuric acid in the refining process, is also being sold for flotation. The sludge acid from coal tar is said to have a flotation value as good as or better than that from petroleum, and even coal tar itself is extensively used because of its low price.

These different products entering into ore flotation may be divided, in a general way, into two classes, known as "frothing agents," which promote foaming, and "collecting agents," the function of which is to coat with a film of oil the mineral particles only, so that, adhering to the air bubbles in the foam, they are thus separated from the gangue. While all oils possess both frothing and oiling or collecting properties in some degree, eucalyptus oil, the pine oils, pine-tar oils (the "light" and "heavy" oils of this publication), and crude turpentine are primarily used as frothing agents. Coal tar, pine tar, together with hardwood tar, and "sludge acid" are used as collecting agents. Success in ore flotation demands a proper adjustment of these two physical properties to the particular requirements of the ore to be treated. While all of the products mentioned can be used in proper combination, with some measure of success, the pine oils occupy a commanding position in the field of ore flotation.

Samples of pine oil and of the crude distillates obtained in the retort work were submitted for flotation tests to the Bureau of Mines Metallurgical Experiment Station, Salt Lake City, Utah, to ore mills in the Coeur d'Alene district, and to the testing department of a large copper mining company. The results from their tests showed that the crude turpentine was virtually as effective a flotation agent as the pine oil, and even the light and heavy oils were applicable, though requiring a greater proportion a ton of slime, especially in the case of the heavy oil. Even the acid liquor was found useful on certain pyrite ores.

Where, therefore, the efforts of the producers were formerly directed toward refining the crude distillate to recover a maximum

quantity of turpentine, the change in market conditions makes it desirable to throw as much of it into the pine-oil fraction as is possible, or to go a step farther and market the entire crude distillate as flotation oil. If this were done it would, of course, reduce decidedly the cost of running the plant, and simplify operation. The consequent reduction in cost of production would probably amount to $2 or $3 a cord.

As to future flotation-oil values it is difficult to conjecture. The Bureau of Mines, which experimented with the various oils obtained in the course of this work, commenting on the conditions that will probably have to be met in the flotation-oils market during the coming years, points out that:

> Pine oil at 50 to 60 cents per gallon has cost too much. Crude petroleum and coal tar containing small additions of pine oil can be made to do almost the same grade of work and are hence cheapening the cost of flotation oils. Pine cresote, pine tar oils, and various hardwood fractions, together with hardwood tar, are finding acceptance in place of the more expensive products. There will always be a market for pine products, however, as long as they do not cost too much; 30 to 40 cents per gallon, f. o. b. the West, will probably be the price paid for such material and when the price goes much above that, the material will merely be eliminated from consideration.

Some idea of the quantities of these pine products used in the flotation of ores may be obtained from Table 20.

TABLE 20.—*Monthly consumption of flotation oils in the United States (1916).*

[Compiled from a report of the Bureau of Mines.]

Type of ore.	Monthly tonnage of ore.		Wood products.				
	Beginning of 1916.	End of 1916 (estimated).	Pine oil.[1]	Pine-tar oil.[2]	Oil of eucalyptus.	Wood creosote.[3]	Crude turpentine.
	Tons.	*Tons.*	*Galls.*	*Galls.*	*Galls.*	*Galls.*	*Galls.*
Copper	1,248,000	1,942,000	7,800	95	.....	47,600	205
Zinc and complex	248,000	350,000	8,000	85	.....	30,000	450
Lead	115,000	136,000	515	.....	28	13,800	.....
Gold and silver	45,700	123,000	1,300	95	.....	4,600	.....
Total	1,656,700	2,551,000	17,615	275	28	96,000	655

[1] Probably includes a considerable amount of the lighter fractions of pine-tar oil.
[2] The crude light oil would probably come in this class.
[3] The crude heavy oil would probably come in this class.

It has been pointed out that combinations of different oils are used by mixing the more expensive pine-wood distillates with crude petroleum, coal tar, etc., in suitable proportions to obtain the desired foaming and collecting effect for the kind of ore to be treated. While this is to a large extent done at concentration plants, some producers in the East market blended oils on this same principle. This should, of course, be given careful consideration by those who may

engage in the production of flotation oils from resinous wood wastes in the Northwest. A list of uncompounded pine oils and other distilled wood products used, either alone or for producing blended oils for flotation, is given herewith. Some idea of the required properties may be derived from the specific gravities:

Crude pine oil.
Crude wood turpentine.
Pine oil, steam distilled (sp. gr., 0.925 to 0.940).
Pine oil, destructively distilled.
Pine-wood oil (light) (sp. gr., 0.950).
Pine-wood oil (heavy) (sp. gr., 1.025).
Pine-tar oil (sp. gr., 1.025 to 1.035).
Pine-tar oil, double refined (sp. gr., 0.965 to 0.990).
Pine tar, thin (sp. gr., 0.980 to 1,000).
Wood (pine) creosote, refined.
Hardwood oil (Michigan) (sp. gr., 0.960 to 0.990).
Hardwood oil (Michigan) (sp. gr., 1.06 to 1.08).

REFINING CRUDE WOOD TURPENTINE.

The crude wood turpentine is a complex mixture of oils, both lighter and heavier than pinene, certain of which impart to the turpentine an objectionable, penetrating odor and dark color, from which wood turpentine having the accepted commercial requirements, and of uniform quality, is to be obtained. To compare favorably with gum spirits the refined product should, in addition to its odor and color, have a correspondingly narrow boiling-point range or distillation-temperature limits.

In refining crude wood turpentine it is customary to subject it to steam distillation, after thorough mixing with caustic alkali to remove or hold back certain constituents, whereby it is separated into a fraction lighter than turpentine, having a yellow color and penetrating odor, a turpentine fraction, and a pine-oil fraction. The details of operation and the proportion and quality of the products thus obtained vary greatly with the quality of the crude oil, as well as with the care observed in dividing or cutting the fractions. In doing this the still operator is commonly guided by the density, odor, color, etc., of the oil in changing over from one fraction to another, which is not conducive to uniformity of results. This insufficient standardization of the product has contributed materially to the unfavorable attitude of consumers toward wood turpentine, as well as to the lower price commanded by and greater difficulty in marketing this product as compared with gum spirits.

The necessity of separating a light fraction that must be marketed as an inferior turpentine or special product because of its objectionable odor and color, moreover, is a wasteful practice, in that this product is made up largely of pinene which properly belongs in the turpentine fraction. Owing further to imperfect fractionation, or the tendency of the heavier oils to pass over with the turpentine, only in part overcome by the use of column stills, a considerable

proportion of the turpentine fraction is retained in the residual pine oil.

Because of these defects in refining processes, efforts were directed in the beginning of this work to devise a laboratory method for recovering a maximum of high-grade spirits from the crude oil that would be applicable to the operation of a commercial plant, on the basis of which yields of commercial turpentine from different woods could be compared. It soon became apparent that sufficient importance is not attached to the amount of alkali required and to the manner of its application. Instructions merely to distil with alkali or to treat with alkali until action ceases are entirely inadequate, because the amount of alkali used materially affects the proportion of the light fraction, the sharpness of the fractionation, and the quality of the turpentine as indicated by its odor, color, and boiling point limits. The intimacy and period of contact of the alkali has equal or greater influence.

The alkali appears to serve a double purpose, aside from that of neutralizing the free acid present in the crude oil. First, it brings an apparent polymerization of the aldehydes whereby these are converted into resinous, nonvolatile compounds, in which form their elimination from the turpentine is effected on distillation. Second, the action of the alkali, if used in sufficient quantity, results in the formation of a soap with the tar and resin acids. This, in a manner not understood, although it may be through formation therewith of a so-called water-soluble oil, restrains the escape of the pine-oil constituents, while the turpentine distils over, thus effecting a materially sharper separation of the two. The alkali solution being immiscible with the turpentine and the polymerization process partaking in its nature of a catalytic or surface reaction, the effectiveness of the alkali depends on extremely intimate contact with the turpentine for a sufficient length of time to permit the carrying of the reaction to completion before beginning the distillation. It is in this respect that refining methods as ordinarily carried out are wrong in principle, for the reason that, with the alkali added in the still, distillation begins before completion of the reactions that "fix" the aldehyde bodies. These in part pass over with the turpentine and are removed from the sphere of action of the caustic solution before the reactions that render them nonvolatile have been completed. Agitation of the turpentine in a separate vessel and removing and distilling the oil thus separated from the alkali are also wrong in principle, because advantage is not taken of the deterring action of the soap solution on the distillation of pine oils.

To combine the action of the two principles here set forth the crude oil is agitated with caustic soda solution at boiling temperature in a return-flow condensing apparatus before distilling. Me-

chanical agitation with a paddle-wheel stirring device was the first resort. It was subsequently found, however, that heating over a flame in a distilling flask fitted with return-flow condenser is equally effective and much simpler in execution. This method of treatment thoroughly emulsifies the oil and caustic solution, giving the intimacy of contact desired, while the inverted condenser continually returns the aldehyde bodies to the action of the alkali until they have been changed to the nonvolatile products previously discussed. The inverted condenser is then replaced by a Hempel column and the contents of the flask distilled with steam, yielding from the start a turpentine of standard requirements.

Steam distillation is admirably adapted to the production of turpentine of uniform quality, because it affords a simple means of control, in that the ratio of oil to water in the distillate is an index of the composition of the turpentine (12). This is a gradually diminishing ratio in proportion as the oil contains less pinene and correspondingly more of the higher-boiling pine oils. For any observed oil-to-water ratio, however, the turpentine has a definite composition, as indicated by its density, refractive index, distillation-temperature limit, etc. This, of course, follows from the law of relative vapor pressure of immiscible liquids. Its application as a simple and remarkably accurate means by which to judge the composition of the turpentine at any time during the distillation, however, has not been given the consideration it merits (12) as a means of standardizing the output of commercial plants. Properly used, the oil-to-water ratio makes possible the production of turpentine having a constant, predetermined composition, any consignment of which will be practically the same as a preceding or subsequent shipment.

Following up preliminary observations, based on the considerations set forth, a series of experiments was conducted to determine: (*a*) The relative efficiency of caustic soda, carbonate of soda, and milk of lime as refining agents; (*b*) the proportion of alkali to crude oil and concentration of the alkali solution giving the best results; (*c*) the time necessary for the reactions set up by the alkali treatment to produce its full effect; (*d*) the effect of drawing off the alkali after treatment and washing the oil with water before distilling; (*e*) the effect of passing a current of air through the oil during treatment with alkali.

In carrying out these experiments 500 cc., taken from a large composite sample of crude western yellow-pine turpentine, were used in each test. The turpentine fraction proper was continued to where the ratio of oil to water was 4 to 6, beyond which the proportion changes rapidly, and a second turpentine fraction collected between the 4 to 6 and 3 to 7 ratios. The distillation was continued for the

recovery of pine oil to the point where the oil constitutes but 5 per cent of the distillate coming over. The odor, color, refractive index, density, where possible, and volume of each fraction thus obtained by the different methods of treatment were noted in order to determine by the comparison of these constants which process gives the closest separation and best yield of high-grade product.

As was to be expected the best results were obtained by the use of caustic soda. With carbonate of soda, used in such proportion that its hydroxyl strength was equivalent to that of the hydrate, the quantity of the turpentine recovered from the crude oil was the same as that obtained with caustic soda, but of inferior quality with respect to odor. For commercial use, moreover, the fact of its being cheaper than the hydrate is offset by its greater equivalent weight and the correspondingly larger quantity required to produce the effect of an equivalent amount of sodium hydrate. Milk of lime has only low cost to recommend it. The calcium resinate or lime soap formed, being insoluble, does not form the pine-oil emulsion that helps materially to effect a sharp separation of the turpentine. The yield of the turpentine is lower by 10 per cent than when sodium hydrate is used, and the product is inferior in odor. Moreover, the lime soap seriously fouls the apparatus with an incrustation difficult to remove.

It was found that the quality improved and the percentage of turpentine recovered increased with increasing amounts of alkali up to 75 cc. of 20 per cent caustic-soda solution per 500 cc. of crude oil, or, in industrial terms, 75 gallons of 20 per cent caustic-soda solution (containing 20 parts per hundred of actual sodium hydroxid) to 500 gallons of crude turpentine. This proportion was found to be satisfactory for refining the crude second turpentine. For the crude first turpentine the amount of alkali probably could be diminished. The concentration of the alkali solution is not so important, since the use of half this quantity of 40 per cent alkali solution does not materially affect the results. The duration of the chemical treatment before beginning the distillation is of great importance, and at least 30 minutes after the mixture reaches the boiling point should be allowed for the completion of the reactions involved. Separation of the alkali solution from the turpentine before distilling has a profound effect. Not only is the quality of the turpentine much inferior to that of the turpentine obtained when the distillation is made in the presence of the alkali solution, but the yield is lower by 20 per cent, with a corresponding increase in the second turpentine and pine-oil fractions, showing that, however brought about, the soap solution exerts a restraining influence over the pine oil, the complete separation of which from the turpentine is most essential to the production of an article possessing the properties demanded by the trade. Passing air through

the oil during the alkali treatment yields a turpentine having a sweeter odor than that obtained without aeration. The other properties and the yield of turpentine recovered, however, are not materially influenced thereby. In refining a crude oil which is heavily charged with the decomposition products of destructive distillation, aeration to improve the odor may be found advantageous.

This procedure was followed in refining the various crude turpentine samples obtained:

Transfer a 500 cc. portion to a round-bottomed liter flask, add 75 cc. of 20 per cent NaOH solution, and some finely broken pumice. Attach a large reflux condenser and heat the contents to and maintain at the boiling temperature, over a gas flame, for one-half hour. When sufficiently cooled, to avoid loss, remove the reflux condenser, attach a Hempel column of fairly good size filled three-fourths full with short pieces of glass tubing, and a condenser in the ordinary position, and distil the contents of the flask with steam in the usual manner. The oil coming over to where the ratio of oil to water is 4 to 6 is first-quality commercial turpentine, ready to enter the trade as such. That coming over between the 4 to 6 and 3 to 7 ratio contains a small proportion of lighter pine-oil constituents, and needs to be distilled a second time for their complete removal. The distillation is continued for the recovery of pine oil to the point where the pine oil forms 5 per cent of the distillate coming over at the time, below which ratio it was not deemed economical to go.

To determine quickly the proportion of oil to water in the distillate it was found convenient to use a coordinate paper diagram (fig. 5), in which abscissæ are the water readings and ordinates the total distillate readings collected during a short interval. Right lines are drawn from the origin of coordinates to intersect, at 100 on the ordinate axis, the points 60, 70, and 95 on the axis of abscissæ, respectively, these corresponding to the percentage of water in the distillate at the transition points. To use the diagram for determining the end of, say, the turpentine fraction, the volumes of water and total distillate are read. The volumes of water are transferred to the horizontal and those of the distillate to the vertical axis. If the intersection falls above the 60 per cent water line, the proportion of oil exceeds 40 per cent, and similar readings are taken at suitable intervals until it falls on the line. Similarly, the 70 and 95 per cent lines determine the end of the other fractions.

The odor and color of the refined turpentine samples thus obtained were noted, the specific gravity and refractive index determined, and a distillation made from which to judge their quality (Table 18).

The distillation temperature limits of turpentine are so susceptible to pressure variation that it is essential, in making such comparisons, to conduct the distillation under normal pressure. The laboratory at Moscow, Idaho, being at an elevation of about 2,800 feet above sea level, it was necessary to increase the pressure in the distilling apparatus accordingly. This is accomplished by means

of the apparatus devised in the Bureau of Chemistry and described in detail in Bureau of Chemistry Bulletin 135, "Commercial Turpentines."

The distillation data, along with the other data thus obtained, bring out a striking uniformity in the physical properties of corresponding samples from various sources, differing, however, from the better quality of wood turpentine from the South Atlantic and Gulf States in their higher, though equally narrow, boiling points.

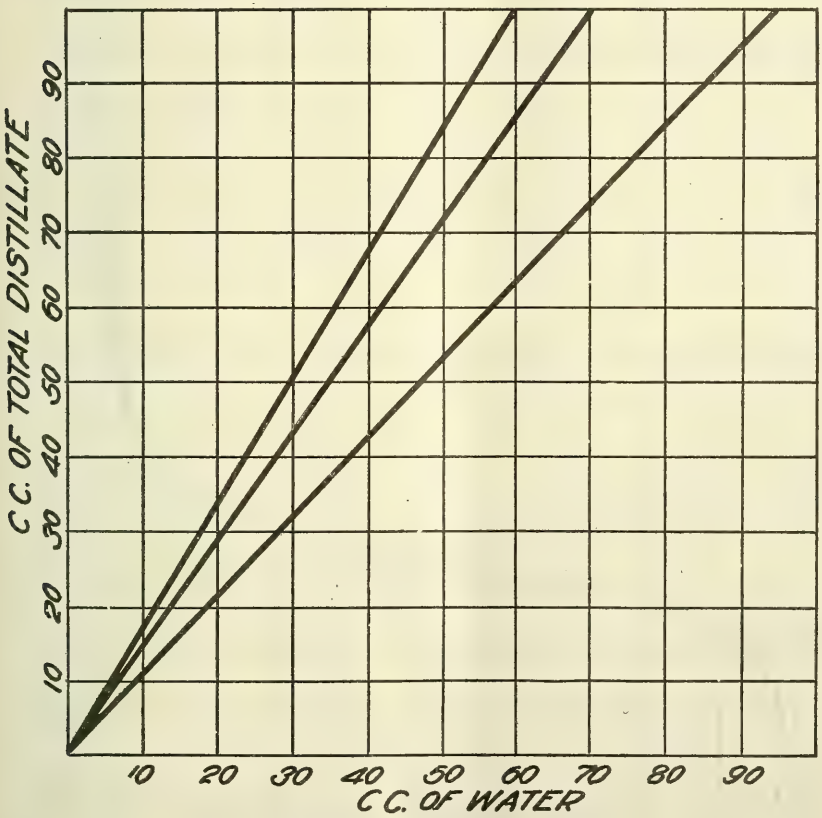

FIG. 5.—Proportion of oil to water in distillate.

The major portion of turpentine from western yellow pine distilling between 170° and 175° C. instead of 160° and 165° C., as is the case with gum turpentine obtained from southern yellow pine, indicates that in place of alpha-pinene this turpentine from western yellow pine is largely made up of beta-pinene (7).

To obtain a closer separation of its constituents, and thereby gain a better insight into the proportion and nature of the bodies probably entering into its composition, a composite sample of refined first-grade turpentine, from first and second crude turpentine combined in

proportions as recovered from the crude turpentine, was carefully distilled from a Hempel fractionating apparatus, and the boiling point, specific gravity, and refractive index curves plotted from these data.

The boiling point, refractive index, and specific gravity curves (figs. 6, 7, 8) point to the presence, to the extent of about 2 per cent,

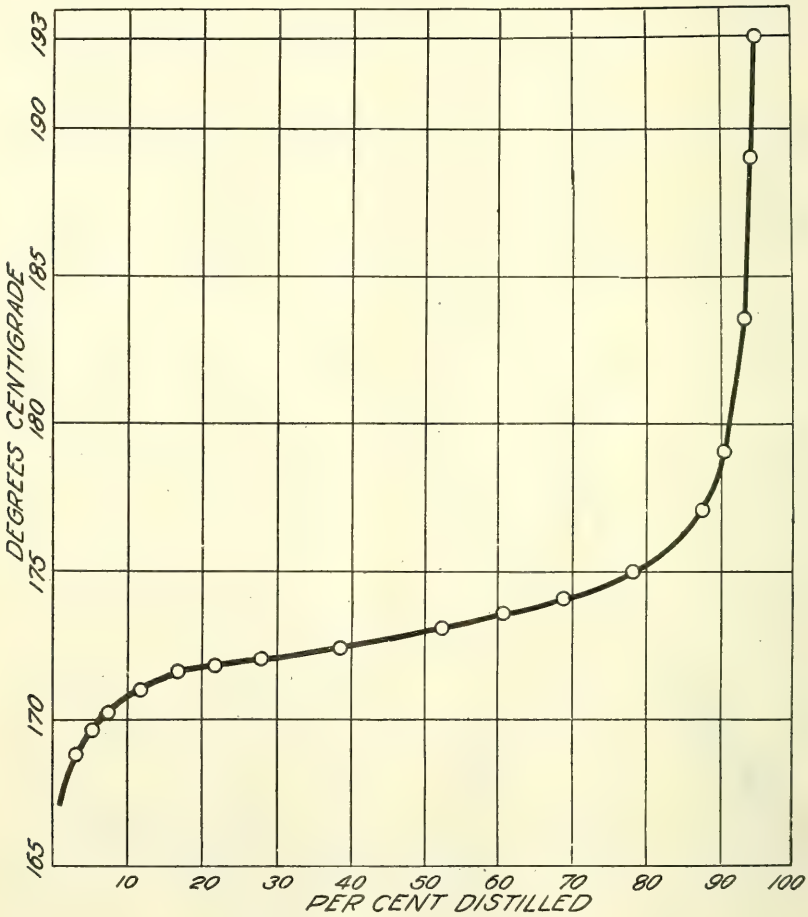

FIG. 6.—Boiling point of distillate.

of a body distilling at a relatively low temperature, having also a much lower refractive index than the major portion of the distillate. This is probably alpha-pinene, which in a pure state has a boiling point of 155° C., a specific gravity of 0.858, and refractive index of 1.4660 at 20° C., whereas the corresponding values of beta-pinene are 162° C., 0.868, and 1.4734. Polarimetric readings on the first two fractions, up to 6 per cent total distillate, showed laevo-rotations, in-

dicating that the pinene present is laevo-alpha-pinene. Subsequent fractions showed dextro-rotations, in a continually advancing degree.

The extra high density of the first distillate to come over is to be attributed to the presence of traces of water, held in solution by small quantities of methyl alcohol, known to occur in this portion of refined turpentine recovered from crude second turpentine, and also partly to the presence of the alpha-pinene. As the distillation pro-

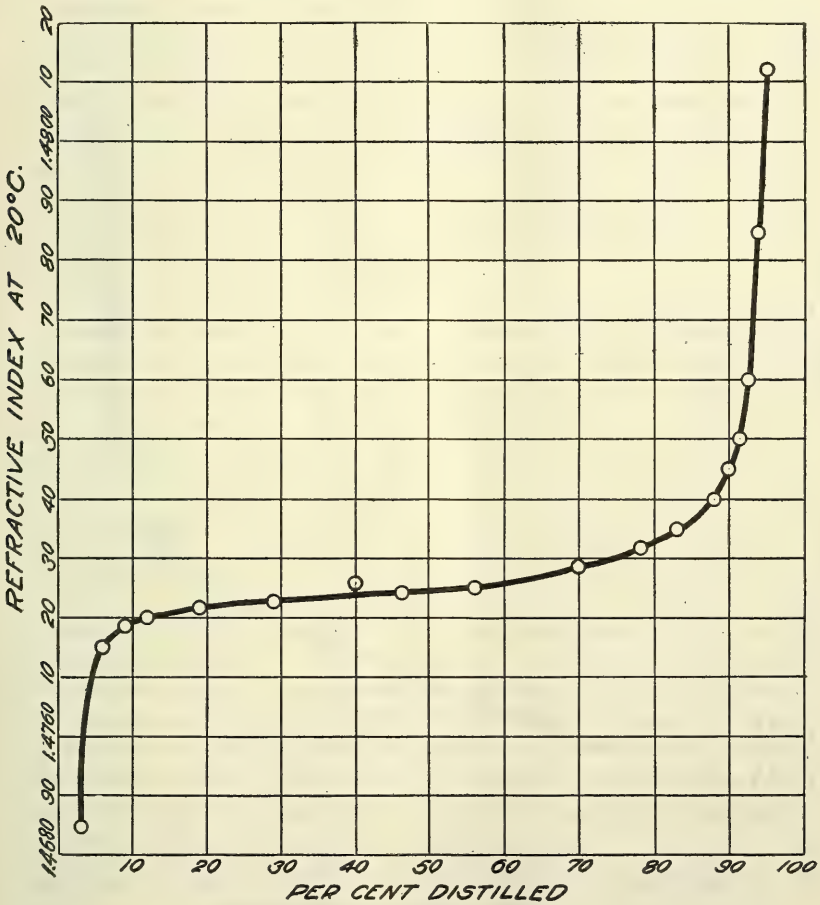

FIG. 7.—Refractive index of distillate.

gresses the specific gravity of the distillate slowly rises with the boiling point to where, at about 20 per cent of total distillate, the presence of a body having a specific gravity lower than that of the distillate immediately preceding it again asserts itself by a bending backward of the specific-gravity curve at this point. This may be due to the presence of one or more of several bodies, the most probable of which is limonene or dipentene (specific gravity 0.845, refractive

index 1.4730, each at 20° C., boiling point 178° C.), dipentene being known to be a constitutent of wood turpentine. A materially higher temperature than the boiling point of betapinene at which, even from the beginning, the turpentine distils, points further to the presence of appreciable amounts of dipentene, the greater portion of the turpentine distilling at a temperature intermediate between that of beta-pinene and dipentene. Above 80 per cent of total distillate the

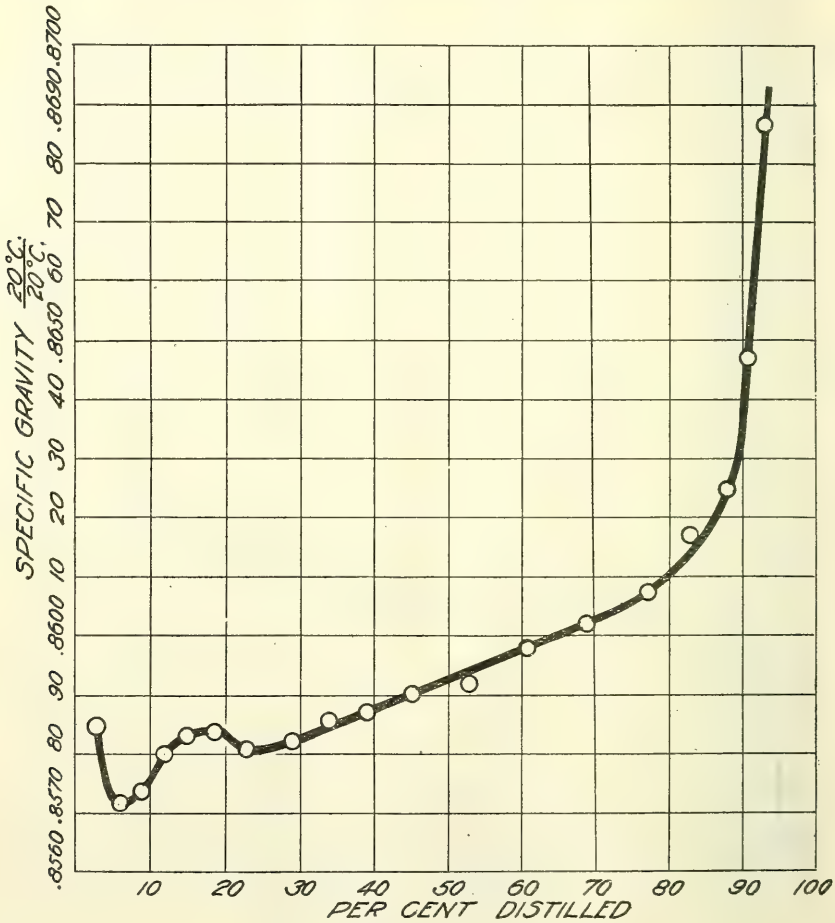

FIG. 8.—Specific gravity of distillate.

boiling point, specific gravity, and refractive index rise rapidly, showing that the composition of the distillate is undergoing a further marked change.

The principal constituents of turpentine, collectively spoken of as terpenes, are a closely-related series of organic compounds possessing such a close similarity in chemical and physical properties that precise knowledge concerning their quantitative estimation has

not as yet been placed on a satisfactory basis. The problem is rendered more difficult because of the tendency exhibited by the terpenes as a class to pass readily from one form to another, and, in addition, to combine with oxygen and the elements of water, under conditions not well understood, to form a series of altogether more complex, oxygenated bodies possessing properties entirely different from those of the parent substance.

Hesitation is felt, therefore, in assigning numerical relations to or making an apportionment of the constituents that appear to enter into the composition of this turpentine further than to say that it seems to be largely made up of beta-pinene and dipentene, or its optically active modification, d-limonene, a small proportion, 5 per cent or less, of alpha-pinene containing perhaps some camphene, and about 15 or 20 per cent of relatively high-boiling terpene derivatives of unknown composition. The boiling-point and specific-gravity curves indicate that the proportion of dipentene, or limonene, probably exceeds that of beta-pinene.

To what extent ordinary turpentine possesses "drying" power, in the sense of being an oxygen carrier, is an open question in the chemistry of paints and varnishes, and the relative oxygen-transferring power of beta-pinene compared to that of alpha-pinene has not been determined. Kremers (5) found that limonene absorbs oxygen quite as rapidly as does pinene, from which it may be inferred that dipentene possesses this property to a like degree.

To what extent the relatively high distilling temperature of turpentine from western yellow pine will influence its value for use in paints, varnishes, etc., can be definitely determined only from actual use. The results obtained in comparative evaporation tests, at room temperature, of gum spirits and wood turpentine from the South, and wood turpentine from western yellow pine, secured in the course of this work, however, show that the product from the western yellow pine is materially slower in evaporating than either the gum or wood spirits from the South. Moreover, the film remaining from the evaporation of the western yellow-pine wood turpentine after drying twice as long as that from either of the others could not, properly speaking, be said to have become dry or resinified, compared with the films from the other samples. This fact is undoubtedly due to the high-boiling constituents, the approximately 20 per cent which distils above 175° C. If this material were not mixed with the turpentine where it does not belong, but were added to the pine oil which it actually is, the turpentine would dry much more rapidly and be more acceptable as a paint and varnish thinner. For some purposes, however, a slow-drying solvent is desired, in which case the presence of the high-boiling constituent is

beneficial. The solvent power of this turpentine appears to be equal to that of turpentine from ordinary sources, and it is quite as light in color. Its odor, while different from that of gum spirits, is in no way objectionable, the main point of distinction in this respect being the pine wood odor so characteristic of the better quality of wood turpentine generally.

While not suitable perhaps for all the technical uses to which ordinary turpentine is adapted, this turpentine will answer for most such purposes and it should find a ready market if properly introduced to the trade.

APPLICATION OF METHOD TO THE COMMERCIAL PLANT.

The method of refining crude turpentine just described is readily adaptable to the commercial plant. Two procedures may be followed, according to the size of the plant and the available capital for investment. The simplest and cheapest equipment for refining the crude wood turpentine is a single copper refining still, so fitted with a water-cooled return-flow condenser and a short fractionating column and condenser, of any efficient type, that either one may be used singly. After suspended and undissolved tarry matter has had an opportunity to settle out, the crude turpentine is drawn into the still, where it is mixed with the proper quantity of caustic soda solution and boiled for the prescribed length of time, with the return-flow condenser open and the fractionating column shut off from the system. The heat for bringing the contents of the still to a boil can be obtained either directly from a furnace under the still or from closed steam coils inside the still at the bottom. The steam coils are the safer arrangement. An open steam coil, with a number of small openings along the length of the coil, is also placed inside the still with the closed coil. This open coil may be connected by a proper arrangement of piping and valves to both the boiler and a small air compressor, and used during the preliminary boiling to aerate the turpentine and alkali mixture.

At the end of the preliminary boiling period the fractionating column is opened, the return-flow condenser closed, and steam turned on in the open-coil system. The turpentine and pine oil are distilled off with the steam and collected in three fractions, as already outlined (p. 58). Toward the end of the distillation additional heat may be supplied by again turning high-pressure steam into the closed coil, to help drive over the last portions of pine oil. At the end of the distillation the alkali residuum is drawn off from the still. The same still may be used for the subsequent refractionation of the various fractions from the first distillation.

A more expensive arrangement, that probably is better adapted to a larger plant, consists of two separate stills, the first of which,

for the preliminary boiling with alkali, is fitted with the return-flow condenser. At the end of the period of boiling the contents are drawn off into a second steam still with a short fractionating column. With this arrangement the operation can be conducted almost continuously. As soon as the charge, after preliminary boiling, is drawn into the steam-refining still, a new charge of crude turpentine can be drawn from the settling tanks into the first still.

In a large plant the final refractionation of the first steam-distilled fractions can very well be carried out in a small continuous fractionating still fitted with a short column.

The alkali residuum, which consists partly of pine and tar oil, with the sodium soaps of tar and resin acids, and an excess of alkali, has been shown by test to have germicidal properties approximately half as great as those of phenol. Its probable use as a local disinfectant, after partial neutralization of the free alkali with the waste acid liquor, is thereby suggested. Probably it can be used, after the addition of a small amount of coal-tar creosote, as the basis of a dip for hogs to rid them of lice. No actual experiments to determine the real value of this material have been made. It is impossible, therefore, to give concise directions for its use.

SUMMARY.

(1) In general, the stumps of western yellow pine are not as uniformly rich in resin as those of the longleaf yellow pine in the South Atlantic and Gulf States.

(2) The only wastes from western yellow-pine logging suitable for profitable distillation on a commercial scale are those resinous stumps which contain at least 50 per cent or more of resinous heartwood, and the resinous heartwood of stumps, dead, down wood, and limbs from which the sapwood has rotted away.

(3) It is impossible to classify western stumps into such grades as "rich" or "pitchy," "medium," and "poor" merely by a superficial examination of the quantity of resinous exudation on the face of the stump.

(4) "Rich" stumps, containing not less than 60 per cent of very resinous heartwood, probably can be profitably distilled in a commercial plant where the stand of such stumps is dense enough to keep a plant supplied for a number of years.

(5) Owing to the fact that there is a well-developed market in the West for crude pine-wood oils for use in the flotation concentration of ores, and also to the small volume of "rich" wood obtainable within hauling distance, it is probable that single retort plants, which can be dismantled and moved when necessary, are the most suitable for wood distillation in that section of the country, espe-

cially in regions remote from the railroad. Such plants might be owned and operated jointly by a number of settlers.

(6) "Medium" grade stumps, though much more plentiful than "rich" stumps, could be used in a commercial plant only at a cost, delivered, materially less than the calculated cost per cord of such wood, $8.37, and at prices for products not materially less than those given in this bulletin.

(7) The refined turpentine from western yellow-pine stumpwood, consisting mostly of beta-pinene and limonene, has higher boiling-point limits than similar turpentine from southern yellow pine, and dries much more slowly. For this reason paints and varnishes thinned with the turpentine take longer to dry than the same paints and varnishes thinned with turpentine made from the longleaf yellow pine of the South.

(8) The solvent power of this turpentine is not less than that of wood turpentine from longleaf yellow pine made and refined by the same process. It is suitable for many if not all of the purposes for which wood turpentine can be employed.

(9) The refined pine oil and the crude oils obtained by distilling western yellow pine are valuable for ore recovery by the flotation process. This is probably the most profitable use to which these products can be put.

(10) The crude light and heavy oils have germicidal properties approximately half as great as those of phenol, for which reason they are useful for shingle stains, wood preservatives, vermin killers, and disinfectants.

(11) The pyroligneous acid or "acid liquor" contains approximately one-fourth the amount of acetic acid, methyl alcohol, and acetone ordinarily recovered from hardwood acid liquor, and is heavily charged with dissolved tarry matter, resembling in all respects the pyroligneous acid obtained in distilling southern yellow-pine wood. At the usual prices, the recovery of these materials at a profit is hardly possible by present methods.

(12) A simple method for the commercial refining of crude wood turpentine, which yields a superior product, has been devised.

The figures given in this bulletin are based on those which prevailed in 1914 and 1915. Prices have increased materially since that time and estimated profits may be more or less. Material changes in the ratio of total cost of production to selling value of products will increase the calculated profits from wood distillation if the value of products has risen faster than cost of materials and of production. Calculated profits will be decreased if the materials and cost of production have increased more than the value of the products of distillation. In order to estimate at any given time the probable

profits from distilling western yellow-pine wood, costs and values must be calculated on the basis of the cost of labor, wood, equipment, overhead, etc., and on the basis of the value of the products, at the time the estimate is made.

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BULLETIN No. 1004

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USE OF WATER BY SPRING WHEAT ON THE GREAT PLAINS.

By JOHN S. COLE, *Agronomist*, and O. R. MATHEWS, *Assistant Agronomist in Dry-Land Agriculture*, with an introduction by E. C. CHILCOTT, *Agriculturist in Charge of the Office of Dry-Land Agriculture Investigations, Bureau of Plant Industry.*

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INTRODUCTION.

Since 1906 the Office of Dry-Land Agriculture Investigations has been conducting experiments to determine the possibilities and best methods of crop production on the Great Plains. Coincident with this work and an integral part of it since 1907 has been the determination of soil moisture in cooperation with the Biophysical Laboratory of the Bureau of Plant Industry. The investigations have been continuous, coordinated, and systematic at 24 field stations,[1] carefully located to be most representative of general as well as local conditions.

While the data from a single station or a single year are valuable in themselves, they are still more valuable in their contribution to the mass of facts accumulated. Covering a long series of years, embracing wide ranges of soils, climatic conditions, and crop adaptations found from the northern to the southern Plains and from the lowest to the highest altitudes within them, the mass of comparable data that have been gathered has a value that while foreseen affords possibilities of study that could hardly have been appreciated when

[1] The stations in Montana, North Dakota, Wyoming, Nebraska, and Kansas are conducted cooperatively with the agricultural experiment stations of the respective States. The stations in South Dakota, Colorado, Oklahoma, Texas, and New Mexico are operated independently by the United States Department of Agriculture.

the work was started. The wide range of the curve of every relation that is plotted may reveal a fundamental principle that could not have been suspected from a single group of the data and makes it possible to test severely hypotheses to which its study leads.

The present study is the first that has been presented in which the data are used to develop a general problem other than one dealing primarily with methods of culture and the results as measured in terms of resulting yield. While it develops effectively the problem it undertakes, it is by no means exhaustive and suggests and invites study of more questions than it endeavors to dispose of. It is only suggestive of the possibilities of such data.

While the importance of an adequate supply of water has long been recognized, the dependence of yield upon an uninterrupted supply has perhaps never before been so well established. Determination of the daily rate of the use of water and the dependence of yield upon the maintenance of this rate lays a foundation for more exact prediction of yields than are possible without such knowledge. In the daily rate of the use of water is to be found a reason for the difference in effectiveness of rainfall in different sections of the Great Plains. The writers have done enough checking of results outside the Great Plains to be satisfied that in the same factor is to be found a basis of comparison and explanation of the results in other sections and under other types of rainfall.

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STATEMENT OF THE PROBLEM.

Dry farming is practiced only in regions where the water available to crops is a factor of prime importance. As the initial water supply stored in the soil and the quantity that may be supplied by rains during the growth period are limited and susceptible of measurement, it is of fundamental importance in any study of the subject to know the daily rate of the use of water by the growing crop and the total consumption by the crop during its life period. In investigational work it has appeared especially important to determine the actual rate of use in the field in order to properly evaluate quantities of water in terms of the length of time they would meet the requirements of the crop.

Other investigators have made exhaustive physiological investigations of the water requirements of crops directed chiefly to the measurement of the water actually transpired by the crop plants alone.

In the field the crop has an initial supply measured by the available water stored in the soil within the zone of depletion by the crop. This is replenished or added to from time to time by the precipitation. The water is used by the crop and by the weeds that accompany it and is lost by direct evaporation and very seldom under dry-farming conditions by leaching. A portion of the precipitation may be lost by run-off.

In the field it is not possible to separate the water actually used by the crop in the sense of passing through the tissues of the plants comprising it from that lost by other means. If it were possible, it does not necessarily follow that it would be desirable. The water

lost by weeds, evaporation, run-off, and other factors is as truly a part of the water used by a crop under a given method of cultivation in any region as is the water actually transpired by the vegetative surface of the crop.

To know the requirements of the crop in the field it is consequently necessary to determine the quantity of water that is lost from the soil and the quantity that is supplied by precipitation. The sum of these quantities for any period constitutes the water used by the crop. When this is known for any period the daily rate of use can be calculated directly from the number of days in the period. Many problems arise in addition to or in connnection with the main one. Some of these are considered in the present study.

SOURCE, CHARACTER, AND METHOD OF STUDY OF THE DATA.

In the 14-year period from 1907 to 1920, inclusive, soil moisture determinations have been made at 23 field stations for a total of 205 station years. While data have been obtained from all the principal crops, the present study is confined to the wheat crop. This has been durum wheat and mostly of the Kubanka variety or type.

From the data available, that from two plats has been selected for the present study: Plat A, continuously spring plowed and cropped to wheat, and plats C and D, which are alternately fallowed and cropped to wheat, so that wheat is grown on one of them on fallow each year.

The data for individual years are not all that might be desired, as they were not taken especially for the present study. Greater intensiveness through more frequent sampling would have added to their value and made possible the use of the data of many years that must be rejected because determinations were not made at the necessary stage of growth or condition of soil moisture, but the cases that can be used make up a volume of observations that probably more than offset the intensiveness that might have been obtained had the work been limited to a smaller number.

All determinations here studied have been made on 1-foot sections of soil.

Soil samples are taken with a tube having a diameter at the cutting edge of 20 millimeters. To determine the water content of a plat four cores are taken from it at locations representing its four quarters. The four cores are handled as two samples, the two cores from opposite corners being placed together. Determinations are thus made in duplicate, each one of the samples being made up of two cores and having a weight of dry soil varying from 200 to 300 grams.

Each core of soil when drawn from the ground is discharged from the tube into a can of sufficient size to hold two cores. The cans are provided with tight covers, which prevent any appreciable errors from loss of water before weighing, even though weighing should be considerably delayed. To facilitate weighing, each can is made to balance a weight of 110 grams. The samples are immediately taken to the laboratory and the net weight determined to the nearest one-tenth of a gram.

After the wet weight is determined the cans are opened and placed in an oven, where they are subjected to a temperature ranging from

100° to 110° C. for a sufficient length of time to expel all water, as determined by their coming to a constant weight.

The dry weight of soil is then determined and the percentage of water to the nearest tenth calculated on a water-free basis by means

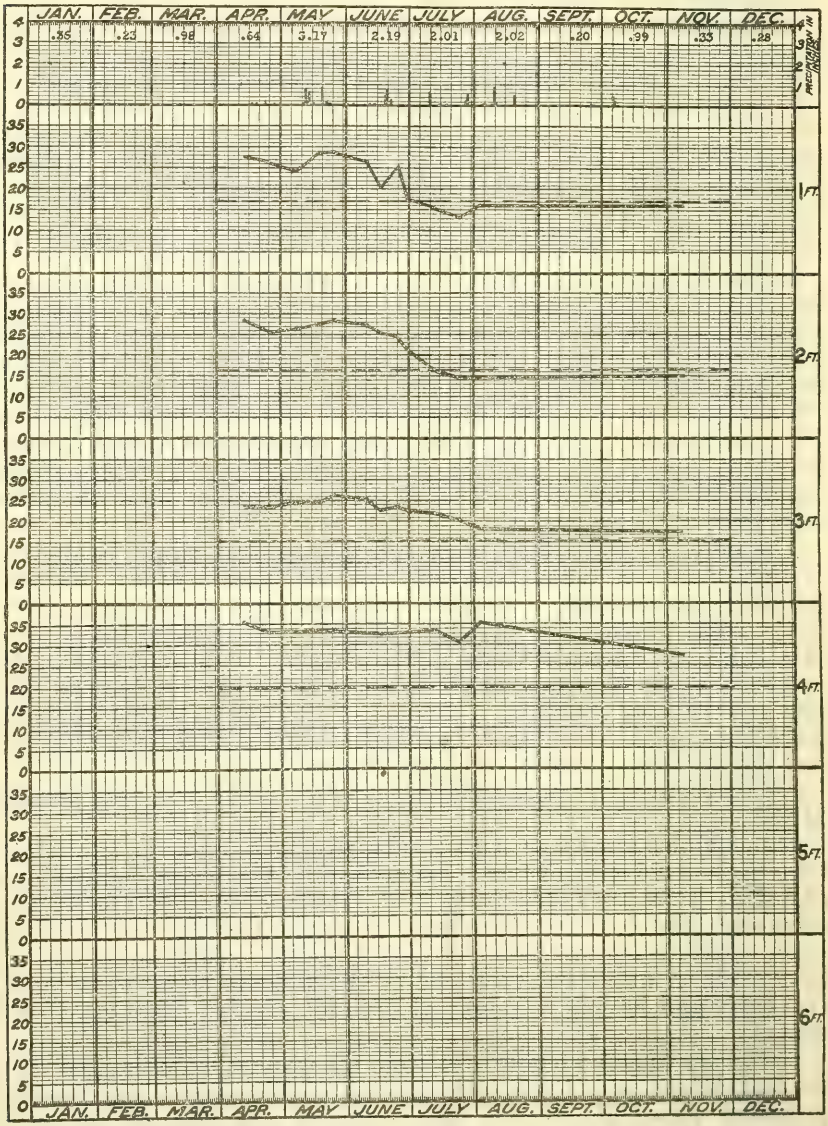

FIG. 1.—Soil-moisture chart of wheat plat C at the Belle Fourche Field Station in 1916. The water content of the upper 4 feet is shown by four curves connecting the points indicating the percentage of water in each foot at each date of sampling.

of a slide rule. The average of the duplicate determinations is the figure used as the percentage of water in the unit at the time of sampling.

For purposes of study the data so obtained are reduced to graphic form by charting on specially designed blanks. Figure 1 is a repro-

duction of the soil-moisture chart for wheat plat C in the continuous-cropping series at Belle Fourche in 1916. Determinations on that plat were made to the depth of 4 feet that year. Its water content at the several dates of sampling is consequently shown by the points of four separate curves. Immediate reduction of these to a single curve by averaging the four would result in an error of a magnitude dependent upon the differences in the volume weight of the several units of soil. Soils of the several stations also differ in volume weight, and consequently any given percentage of water content may not indicate the same actual quantities of water in different soils or soil units. Further, it is not possible directly to combine percentages of water in the soil with inches of water added to it by rainfall during any period. Consequently it has been necessary to convert the percentage of water in each foot section of soil to terms of inches of water.

Prerequisite to such conversion is the determination of the volume weight of each soil unit under study. This has been determined by calculation from the weight of the cores taken by the soil tube. For this determination periods were selected when the soil tubes were known to be new and in good condition with a sharp cutting edge of a circle of the known diameter of 20 millimeters. As large a number of weights as possible, not less than 50 and preferably more than 100, were averaged for each unit, and the weight per cubic foot was calculated from the weight of a known volume. Weights of obviously defective cores were arbitrarily rejected. It is believed that the volume weights determined by this method are as accurate as those that might be determined by any other method based upon a smaller number of cores of larger volume. The volume weights so determined and used as bases of conversion have been carefully considered in the light of all knowledge and information on the several soils and accepted as fair bases of comparison.

This study is concerned with the amount of change in the water content of the soil during a period rather than with the actual water content. The process, therefore, has been to determine the percentage of change and then to convert this into inches of water, instead of reducing the entire water content to inches and then determining the change by subtraction.

In determining the water loss from the soil for any period the first step is to subtract the water content of each foot section at the end of the period from the water content of the same unit at the beginning of the period. At this time the water content is expressed as a percentage of the dry weight of the soil. The next step is to convert these expressions to terms of inches of water by calculation from the determined weights of the soil of each unit. An increase in water content is recorded as a minus loss. The algebraic sum of the losses from all the units (foot sections) involved is the loss from the soil of the plat under determination.

The total water loss or the total water used by the crop in any period is determined by adding the precipitation for the period to the water lost from the soil. It is the algebraic sum of the two quantities. The relative importance of the two quantities will be considered later, and the necessity of combining the two into a single quantity will be shown.

There is, of course, a considerable number of experimental errors in the determinations. Even in the most uniform soils, duplicate determinations of soil moisture are nearly certain to vary at least one-half of 1 per cent, and in less uniform soils variations of much greater magnitude occur. The probable error of the total of any individual sampling or of the difference between the totals of any successive samplings may be relatively large or small, depending upon the dispersion of the errors of the units making up the totals and the extent to which they compensate each other. An error in the same direction of one-half of 1 per cent in each foot in a determination to the depth of 6 feet on a soil weighing 75 pounds per cubic foot would be equivalent to 0.42 inch of water. In soils lacking uniformity the experimental error may be much larger.

In the present study of the use of water the following practices have been followed for the purpose of reducing the experimental error as much as possible:

(1) The depth to which the samples have been included in each determination has been limited to the zone of change of water content. For example, even if samplings have been made to the depth of 6 feet or more but all changes in water content (either reduction by use or addition by rainfall) have been confined to the first 3 feet of soil, the calculations to determine the quantity of water used have been limited to 3 feet. Inclusion of additional depths would only increase the experimental error without contributing anything of value to the results.

(2) Periods of time as long as practicable have been used to determine the rate of use in each instance.

To obtain the rate of use per day, the quantity of water used in any period is divided by the number of days in that period. Any error that may exist in the total quantity of water used is consequently reduced in proportion to the number of days in the period. In a general way, experimental errors of successive samplings tend to compensate each other, and the experimental error for the quantity of water used in a season should be small and is limited to the errors in the first and last samplings.

DAILY RATE OF THE USE OF WATER WHILE THE CROP IS GROWING RAPIDLY.

Under this heading are included the results of attempts made to determine the daily rate of the use of water by the wheat crop under full and uninterrupted growth. This rate was calculated in all years when two soil-moisture determinations at least two weeks apart were made during the period of rapid growth of the crop and while it was not suffering for lack of water. As long a period as possible was selected for each year, in order to make the error in the rate per day due to the experimental error of the determinations as small as possible. In years when no shortage of water occurred the end of the period is determined by harvest. No years were included (1) when the crop had suffered from drought before the period of rapid growth was reached; (2) when the second sampling during the rapid-growth period was delayed until after the crop commenced to suffer from drought; (3) when some condition, such as hail, rust, or insects, destroyed the crop. Years when some factor other than a lack of water was responsible for crop injury were excluded, to avoid the

introduction of irrelevant data in a correlation of the rate of the use of water with the yield.

There remained 53 years in which the daily rate of the use of water could be determined under the conditions imposed. These are distributed among 14 stations located in the Great Plains from Huntley, Mont., and Williston, N. Dak., on the north, to Amarillo, Tex., on the south. Two of these stations—Ardmore, S. Dak., and Garden City, Kans.—furnished data for only a single year each, while at Edgeley, N. Dak., a measure of the rate was determined for 10 years.

The rate was determined separately for two cultural methods at each station. The one designated plat A is continuously spring plowed and cropped to wheat. The one designated plat C or D is alternately summer fallow and wheat. This method occupies two plats, so there is available for study each year a crop of wheat growing on land bare summer tilled the previous year.

In the average of conditions this method contains more water in the soil at the time the crop commences rapid growth, supports a heavier growth of vegetation, and produces a larger crop than the plat continuously cropped, but exceptions are to be noted when one or more of these conditions are reversed.

The results of this study are presented in Table 1. This gives the station, the year, the dates of the soil-moisture determinations marking the beginning and end of the period, the average daily precipitation during the period, the average daily evaporation from a free water surface during the period, the daily rate of water use and yield of plat A, and the daily rate of water use and yield of plat C or D.

The daily rate of water use has been charted with calendar dates as abscissa and total use as ordinates. The slope of the curve then indicates the rate of use. This chart is not presented, because a considerable part of its value for study lies in the identification of each line with the year and station it represents. It is impracticable to attempt this on the scale to which it necessarily would be reduced in publication. Such charting shows that the rate of use is not determined by the dates within which or the part of the period of rapid growth during which the rate was determined. This phase of the subject is more fully developed in the study of the rate of the use of water during the season. In this it is shown that after beginning rapid growth, about the time tillering is completed, the rate of use remains fairly constant until harvest if not interrupted by failure of the water supply or by some destructive or inhibiting agency.

These determinations afford opportunity for a study of the relative importance of water from the soil and of precipitation in determining the rate of use and for the examination of the reasons for combining the two to obtain this rate.

The material has been studied in various ways. Charting the two quantities and the total which they make up shows very clearly that they are complementary. Under given conditions a given crop requires a certain quantity of water. If this is supplied by precipitation the quantity of water in the soil will not be reduced, and if more than the required quantity is supplied it will be increased; but if the rainfall is not sufficient to meet the demand the available

water in the soil will be reduced by the required difference. This is perhaps best shown by correlations.

TABLE 1.—*Average daily precipitation, evaporation, and rate of use of water by the wheat crop, together with yields per acre, on plats A and C or D during a designated period of rapid growth at the several experiment stations for the years shown.*

Station and year.	Period.		Precipitation.	Evaporation.	Plat A.		Plat C or D.	
	From—	To—			Water use.	Yield.	Water use.	Yield.
			Inches.	*Inches.*	*Inches.*	*Bushels.*	*Inches.*	*Bushels.*
Huntley:								
1913	June 11	June 28	0.11	0.20	0.10	16.0	0.17	22.6
1914	June 13	June 27	.14	.18	.16	18.3	.23	19.5
1915	June 19	Aug. 7	.08	.18	.17	24.5	.20	36.5
Williston:								
1911	June 8	June 24	.04	.25	.10	2.7	.14	7.6
1912	June 12	July 29	.10	.20	.16	25.2	.21	39.7
1914	July 2	July 27	.07	.24	.23	23.8	.30	31.2
1915	May 29	July 12	.07	.21	.12	19.3	.17	27.7
Dickinson:								
1908	June 2	July 22	.09	.22	.19	24.3	.20	33.8
1909	June 3	Aug. 5	.08	.17	.16	26.8	.19	35.7
1910	June 4	July 19	.08	.26	.16	17.4	.21	26.8
1911	June 3	June 16	.05	.22	.13	5.7	.21	23.3
1915	June 11	Aug. 28	.11	.16	.10	25.8	.20	38.7
Mandan:								
1915	June 29	Aug. 23	.12	.18	.11	30.5	.13	39.3
1916	July 7	Aug. 8	.11	.23	.18	19.2	.18	21.8
Edgeley:								
1907	July 1	July 16	.11	.19	.11	4.1	.13	9.9
1908	June 3	July 8	.06	.18	.21	13.3	.18	16.0
1909	June 2	July 19	.06	.14	.16	28.3	.15	27.0
1910	June 2	June 22	.08	.21	.13	4.0	.10	5.7
1911	June 5	June 26	.03	.24	.16	0	.16	0
1912	June 7	July 2	.15	.16	.23	35.0	.20	30.3
1913	June 20	July 29	.11	.19	.15	16.3	.19	16.8
1914	June 23	July 29	.12	.21	.18	11.3	.18	13.0
1915	June 11	Aug. 13	.13	.15	.17	34.8	.16	40.3
1916	June 9	July 29	.10	.16	.18	5.5	.17	6.8
Hettinger:								
1912	May 29	June 26	.04	.20	.18	14.3	.22	17.5
1913	June 21	July 9	.13	.25	.15	13.8	.18	37.0
1915	June 10	July 23	.21	.16	.17	40.7	.22	37.4
1916	May 27	July 5	.08	.16	.10	4.2	.14	4.2
Belle Fourche:								
1909	June 5	Aug. 3	.13	.23	.20	23.8	.21	32.2
1910	June 2	June 16	.04	.25	.18	2.8	.23	5.0
1913	June 18	July 2	.09	.22	.12	6.2	.14	16.8
1914	June 10	June 27	.06	.24	.13	4.0	.18	15.8
1915	June 25	Aug. 5	.16	.18	.17	56.5	.17	57.2
1916	June 10	July 12	.08	.20	.16	10.6	.21	18.7
1917	June 9	July 9	.02	.27	.11	4.4	.11	11.1
1918	June 5	June 24	.01	.23	.13	8.5	.19	35.0
Ardmore:								
1916	June 19	July 29	.06	.27	.21	18.0	.20	15.8
Scottsbluff:								
1913	May 18	June 18	.06	.25	.16	12.0	.19	17.3
1917	June 7	July 6	.04	.30	.19	9.2	.23	18.7
North Platte:								
1908	June 3	Aug. 5	.15	.24	.18	22.7	.22	40.5
1909	June 4	Aug. 2	.17	.24	.25	23.0	.26	18.0
1915	June 4	Aug. 11	.17	.21	.20	22.7	.25	27.8
1916	June 9	July 20	.08	.29	.17	17.2	.20	19.7
Archer:								
1915	June 28	July 28	.04	.21	.17	26.8	.15	25.7
1917	June 4	July 17	.02	.26	.12	15.6	.14	14.9
Akron:								
1908	June 9	June 30	.07	.29	.24	17.3	.23	13.7
1909	June 2	July 28	.12	.27	.18	14.3	.22	18.5
1910	May 25	June 21	.05	.31	.18	11.3	.20	8.5
1912	June 4	July 6	.11	.23	.21	21.3	.21	16.0
1915	June 28	Aug. 12	.10	.21	.17	26.3	.16	33.8
Garden City:								
1909	May 28	June 25	.12	.29	.17	2.1	.22	6.7
Amarillo:								
1911	May 22	June 22	.22	.34	.24	7.3	.33	19.0
1914	May 21	June 13	.05	.30	.23	11.0	.26	13.8
Average			.09	.22	.17	17.0	.19	22.4

The correlation between the total quantity of water used per day and that portion of this quantity that is obtained by reduction of the water content of the soil (designated daily use from soil) is 0.48± 0.07 for plat A and 0.57±0.06 for plat C or D. The correlation between the total quantity used per day and that portion of this quantity that is supplied by precipitation during the period under study is 0.30±0.08 for plat A and 0.29±0.08 for plat C or D. Both these are positive correlations, but the correlation of the total quantity with the precipitation is of a low order. The higher correlation of the total with the portion obtained from reduction of the soil water content indicates that under the conditions specified for this study the stored water is a more dependable source of supply than the precipitation.

The correlation between the two parts that make up the total daily rate of use (the rate of use from the soil and the precipitation) is a negative one of −0.73±0.04 for plat A and −0.67±0.08 for plat C or D. This is a rather high correlation and expresses the high degree to which the two parts that make up the whole are complementary, as previously explained.

Table 1 shows the rates of the use of water per day varying in individual years at individual stations from 0.10 to 0.33 inch per day. That these differences are largely real differences and not experimental error is indicated by the agreement between the two plats. The rate of use may not be the same on the two plats in any year, because they may be supporting different amounts of vegetation, but changes from year to year are in nearly every case in the same direction on the two plats. The rate of water use for any year is undoubtedly not correct to within 0.01 inch and in some cases the error may be several hundredths of an inch, but the use of as long periods as possible for each year and the inclusion of as many years as possible in the data should make the average results for a station reliable.

The 53 station years studied show an average rate of use of 0.17 inch per day on plat A with an average yield of 17 bushels per acre, and an average rate of 0.19 inch per day on plat C or D with an average yield of 22.4 bushels per acre. In some cases the rainfall during the period under study has been greater than the quantity of water used, meaning that the quantity of water in the soil increased, and in other cases the rainfall has contributed as little as 0.01 inch per day to the total. The average rate of rainfall was 0.09 inch per day.

Some points may be shown more clearly by assembling the average rates of use per day for each station in a separate table. This is done in Table 2, which gives the average rates of use per day for both plats A and C or D at each station. In this table, as in Table 1, the stations are arranged as nearly as may be with respect to their geographical location, the more northern ones at the top of the table and the more southern ones at the bottom. This table shows immediately for plat A the dependence of the rate upon the geographical location. The northern stations show in general lower rates of use than the southern. Exceptions are to be noted in the case of the record of a single year at Ardmore, which shows a higher rate than its location would indicate, and a single year at Garden City, which has a low rate. This low rate was made by a very light crop and should not therefore be considered as an exception. The

average rate of use at Archer agrees with the rate in North Dakota and South Dakota. This station is located at an altitude of more than 6,000 feet and has a summer temperature, evaporation, and other climatic factors more nearly like the Northern States than stations in the same latitude.

TABLE 2.—*Rate of the use of water per day during a period of rapid growth on both plats A and C or D averaged for each station.*

Station.	Use of water.		Station.	Use of water.	
	Plat A.	Plat C or D.		Plat A.	Plat C or D.
	Inch.	*Inch.*		*Inch.*	*Inch.*
Huntley	0.14	0.20	Ardmore	0.21	0.20
Williston	.15	.21	Scottsbluff	.18	.21
Dickinson	.15	.20	North Platte	.20	.23
Mandan	.15	.15	Archer	.15	.15
Edgeley	.17	.16	Akron	.20	.20
Hettinger	.15	.19	Garden City	.17	.22
Belle Fourche	.15	.18	Amarillo	.24	.30

With plat C or D the regional effect is more obscured by the influence of the size of the crop on the rate of use. It is most fully exemplified in the high rate at Amarillo, which averages 0.3 inch per day. This is the average of the rates of 0.33 inch and 0.26 inch, respectively. One of these is the highest yet determined and the other has been equaled only once, which was at North Platte in 1909. The rates of use at North Platte and at Garden City also average high in comparison with those at more northern stations. Archer has a comparatively low rate on this plat, the same as on plat A.

In general terms, the average rate of use on plat A ranges from an average of 0.15 inch per day at the northern stations to 0.24 inch at the most southern station and on plat C or D from nearly 0.2 inch per day at the northern stations to 0.3 inch at the station farthest south. The most southern station therefore shows a daily rate of use from 50 to 60 per cent greater than the northern stations.

The averages of plats A and C or D show a relation between the rate of use and yield. A close correlation between the two should not be expected, because the rate of use of water was determined for a period that covered only part of the life of the crop.

In many cases the crop suffered severely from drought at some time after this rate was determined. Other factors, such as extremely hot weather, may have influenced it after the rate had been determined. It was thought, however, that if any relation between the rate of use of water and yield existed, it would be shown through a positive correlation, even though the correlation might not be strong.

The first correlation was made by using the average yield and the average rate of all stations as bases from which to compute departures. The resulting correlation for plat A was 0.24, with a probable error of ± 0.09. This is a very weak correlation and only indicates that a relation may exist. It was not thought possible that a close correlation can be arrived at in this way. The facts that the northern stations yield heavier than the southern ones and

that a rate of use of water that represents a maximum at a northern station is only an average rate at a southern station preclude the possibility of this correlation being close.

To determine whether a closer correlation existed if the difference between the stations could be eliminated, a second study was made. In this second study the average rate of the use of water for each station and the average yield of each station were used as bases for computing departures. Determined in this manner, a correlation of 0.4 with a probable error of ± 0.08 was shown for plat A. This is much closer than the previous one and shows clearly that a much closer correlation between water use and yield exists at the individual station than is shown for the Great Plains as a whole. This correlation is marked enough to show that a relation between the rate of water use and yield actually exists, though it does not indicate how close the relationship may be.

It is probable that a closer correlation exists between the potential yields and the rate of the use of water. In other words, if all the crops from which these data were obtained could have been carried through to harvest without suffering from drought, the ones showing the higher rate of water use would have produced the higher yields. This is, of course, a matter of opinion and can not be subjected to any mathematical test. It is worthy of note, however, that years in which heavy straw growth has been noted almost invariably have been above the average in the rate of water use.

An attempt was made to correlate the rate of water use with the evaporation, as controlled water-requirement studies have shown that evaporation is one of the strongest factors in determining the quantity of water needed by the crop.

It was found that while, in general, stations with a higher evaporation showed the greatest rate of use of water, little relation was shown between evaporation and the rate of water use for different years at the same station.

This was accounted for by the fact that the water lost from a plat in a season of low evaporation may exceed that lost in one with a high evaporation. The water lost from the wheat itself is undoubtedly higher in years with high evaporation. This has been conclusively proved by investigations of the water requirements of crops. The water lost from the soil, however, may be much smaller. As a rule, years having a high evaporation are dry, and the quantity of surface moisture or moisture near enough to the surface to be affected by evaporation is small. Low seasonal evaporation is usually accompanied by frequent rains. When these occur there is a great deal of water that is subject to loss by evaporation from the surface. In spite of the fact that the rate of evaporation from a free water surface is low, considerably more moisture may be lost from the soil by evaporation in years of this type than in years having a high rate of evaporation.

RATE OF THE USE OF WATER AS THE SOIL MOISTURE APPROACHES DEPLETION.

This study was made for the purpose of finding whether the rate at which the wheat crop is able to use water from the soil decreases as the water content of the soil nears depletion.

To determine this point the rate of the use of water for the period when the moisture content of the soil neared depletion was compared with the rate of use of water for the two periods preceding. The conditions necessary for obtaining data on this point were as follows: (1) All three periods must have been within the period of rapid growth, (2) the last period must have ended before the soil moisture was depleted, and (3) the samples must have been taken deep enough to include all soil in which a change in water content took place.

The number of years in which data on this point could be obtained was small, and the experimental error due to the short lengths of the periods was large. In order to obtain data for the consecutive periods within the period of rapid growth, the three periods selected were necessarily short. Data were obtained for an average of about two years at each station.

It was found that when the results of all stations were averaged the use of water for each period was nearly the same. It can not be said that anything conclusive was shown by the data, however. The experimental error in the rate of use per day was so large that it obscured any small differences there might have been between the different periods. No consistency in water use in the different periods is shown either between the different stations or the different years at the same station.

The conclusion drawn from this study is that though there may be a slight decrease in the rate of use of water as the soil becomes drier, such decrease is too small to be measured by the means employed. The wheat crop can exhaust nearly all the available water without any serious reduction in its rate of use.

RATE OF THE USE OF WATER DURING THE GROWING SEASON.

Under the second preceding heading the rate of the use of water under certain conditions and for a part of the growing season was considered. The conditions were such as to permit or require the use of water at maximum rates per day. Under the present heading the rate of the use of water for the entire growing season under conditions that obtain for the entire season will be considered.

The use of water was determined, in terms of inches used, for each period between successive samples, beginning with the one nearest seeding time and ending with the one at or near harvest. The same method was used as in the preceding study. While the primary calculation was in terms of use for each period, the material so obtained was prepared for use by successive additions of the water from period to period. The sum at any sampling date represents the total quantity of water used by the crop from the first date of sampling until the date in question. The successive sums from date to date show the cumulative use of water during the growing season from zero at the beginning to the total quantity at harvest time.

The data so assembled were further prepared for study by charting on cross-section paper with calendar dates as abscissa and quantities of water used as ordinates. The first sampling is indicated by a point on the zero line of ordinates at the given date. The second sampling is indicated by a point the abscissa of which is the date and the ordinate of which is the quantity of water used to that date.

In the same manner the water used from the first sampling until each date is indicated. The points are then connected by a line. The slope of the line between successive points shows the rate of use during the period it covers.

The use of water by more than 100 wheat crops has been determined and charted. It is not considered necessary to reproduce all these charts. A sufficient number will be reproduced to show the types of curves representing different seasons and localities. This purpose is adequately served by charts showing the water use at Dickinson, N. Dak., Akron, Colo., and Amarillo, Tex. These stations are representative of the northern, central, and southern sections of the Great Plains.

The use of water at Dickinson, N. Dak., for the years 1909, 1910, and 1911 on plat A, a spring-plowed plat cropped continuously to wheat, is shown in Figure 2. The year 1909 was exceptionally favorable to wheat. There was no time during the season when the crop

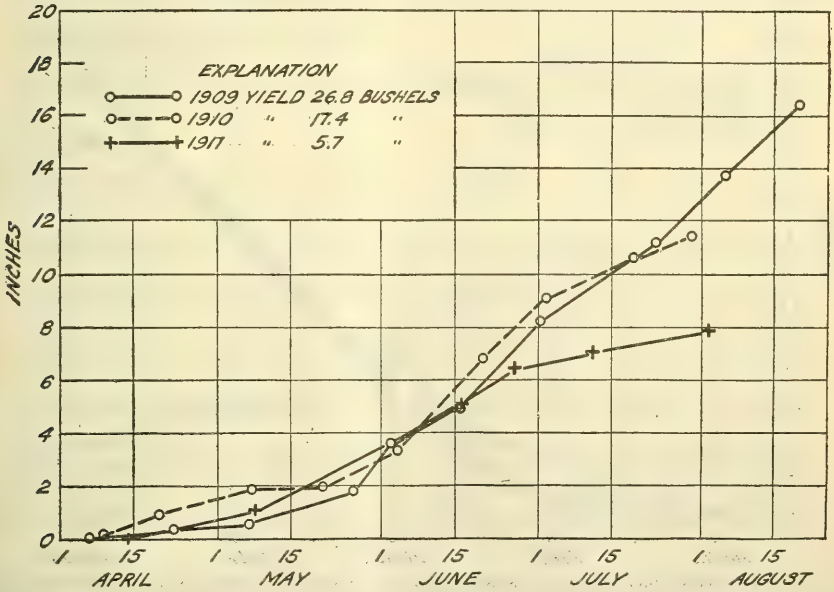

FIG. 2.—Diagram showing the use of water by the wheat crop on plat A at Dickinson, N. Dak., for the years 1909, 1910, and 1911.

suffered for lack of water. As a result, it made a good growth and continued to use water at a rapid rate for a long time. The rate of the use of water from about June 1 to harvest is nearly constant. The year 1910 was not so favorable. The wheat crop commenced to use water rapidly, but the water supply began to run short early in July. The rain in July was sufficient to keep the crop from being badly damaged by lack of water, but there was some suffering that was reflected partly in a slightly lower rate of use near harvest but more particularly in a forced ripening of the crop and an early date of harvest. The year 1911 was one in which the crop suffered for lack of water or lacked sufficient water to make much growth during practically all of its growing season. Except for a short time in the early part of June, there was not enough moisture in the soil to

keep the crop growing rapidly. However, the early drought checked the growth of straw, and the crop, by reason of its meager straw growth, was able to maintain life until harvest on the rains that fell and to mature a small yield of grain. This condition is indicated by the curve (Fig. 2), which shows a comparatively low rate of use throughout the season.

The use of water by the plat of wheat grown on fallowed ground at Dickinson in the years 1909, 1910, and 1911 is shown in Figure 3. It will be noted that the 1909 curve for this plat is practically the same as the one for plat A shown in Figure 2. The curve follows the same general line and there is the same long-continued use of water and resulting high yield. The actual date of harvest was several days later than for plat A, but the final soil-moisture determination was made on the same date on both plats. In both 1910 and 1911 the water use was continued at a rapid rate practically until

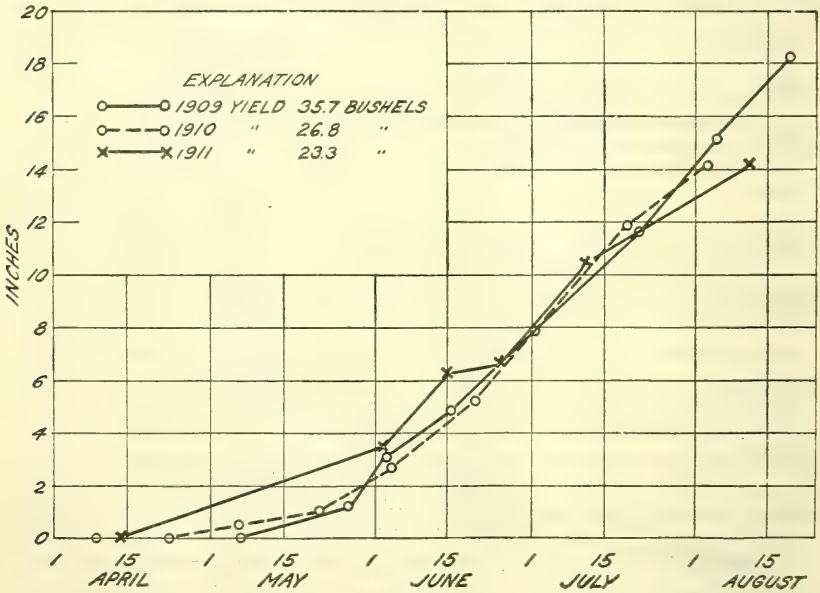

FIG. 3.—Diagram showing the use of water by the wheat crop on plat C or D at Dickinson, N. Dak., for the years 1909, 1910, and 1911.

harvest. This plat ripened a little prematurely in both years on account of drought, and both years show a shorter rapid-growth period and a lower yield than in 1909.

The most noticeable difference between the two charts is in the behavior of plat C or D and plat A in 1911. Plat A suffered for water at nearly all times during the season and was able to mature only a small yield of grain. Plat C or D, by reason of the water stored in the soil through fallowing the previous year, was able to make a good growth and mature a good yield of wheat. It consequently shows a much higher rate of use of water than plat A throughout the season.

Figure 4 shows the use of water on plat A at Akron, Colo., for the years 1909, 1911, 1912, and 1913. Two of these, 1909 and 1912, were good years for wheat. In 1909 the wheat was planted late and did

not reach the period of rapid growth as early as in other years. From the time it commenced rapid growth until harvest the crop did not suffer greatly for lack of water, and there was a resulting good yield. While the yield of 14.3 bushels per acre is not high, it is fair for the locality and as high as could be expected from wheat planted as late as April 23. In 1912 the crop commenced to use water rapidly earlier than in 1909 and used it at practically the same rate. The determination on May 16 represents an extreme example of experimental error. In this case it is evident that the rate of water use shown from April 27 to May 16 is too high, and that from May 16 to June 4 too low. It is due to the fact that the soil samples taken on May 16 showed a lower percentage of moisture

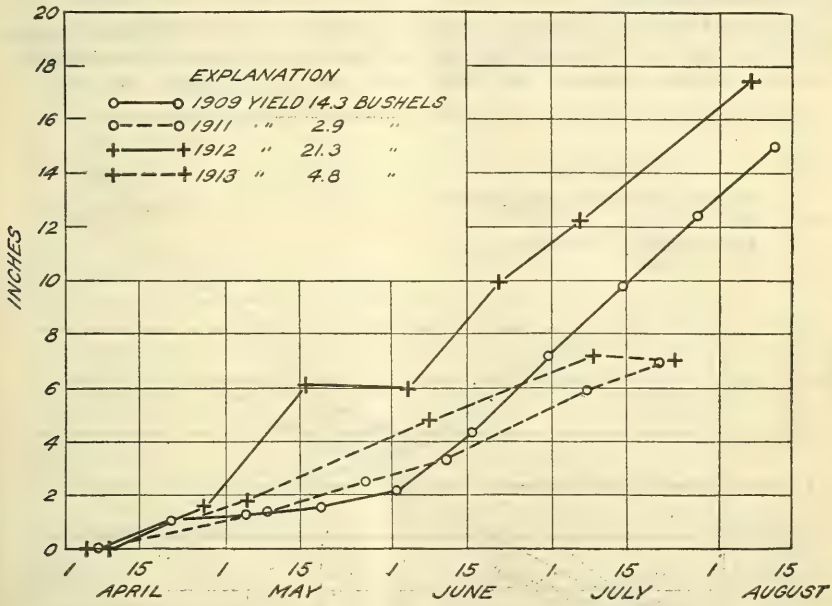

FIG. 4.—Diagram showing the use of water by the wheat crop on plat A at Akron, Colo., for the years 1909, 1911, 1912, and 1913.

than later conditions indicate were warranted. The years 1911 and 1913 both represent seasons when the wheat crop suffered for moisture from the time it began rapid growth until harvest. In both years there is a resulting low rate of water use and low yield shown. Likewise, there is an earlier harvest date than in the two years that were favorable for wheat.

Figure 5 shows the water use on plat C or D at Akron, Colo., for the same years shown in Figure 4 for plat A. The year 1909 was favorable for wheat, and the wheat did not suffer for water at any time during its growing season. That it did not yield more than 18.5 bushels per acre was doubtless due to the late date of seeding. In 1912 the crop actually ran out of water before harvest, and the result is shown in the lower use of water and the slightly lower yield. From the figure it would appear that the date of harvest was later in 1912 than in 1909. The crop in 1912 actually was harvested on August 9, but no soil samples were taken on this plat until August 16. In all other cases soil samples were taken within

two days of the harvest date. The years 1911 and 1913 were unfavorable for wheat. In both these years there was enough water in the fallow plat to start the wheat growing rapidly, but in both years the crop soon commenced to suffer from drought, and the resulting lower rate of water use and low yield are shown. Harvest in both of these years was earlier than in the favorable years.

A comparison of the two figures shows one striking fact. The wheat on plat A in 1912 used more water than the wheat on plat A in 1909 and made a considerably higher yield. On plat C or D the quantity of water used in 1909 was greater than in 1912, and the yield was higher. For the quantity used, the crop on both plats in 1909 shows a lower yield than in 1912. This is probably explained by the later seeding.

A comparison of Figures 4 and 5 shows how ineffective in the growth of spring wheat fallowing has been as a means of combating drought at this station. In 1909, 1911, and 1913 there was only a

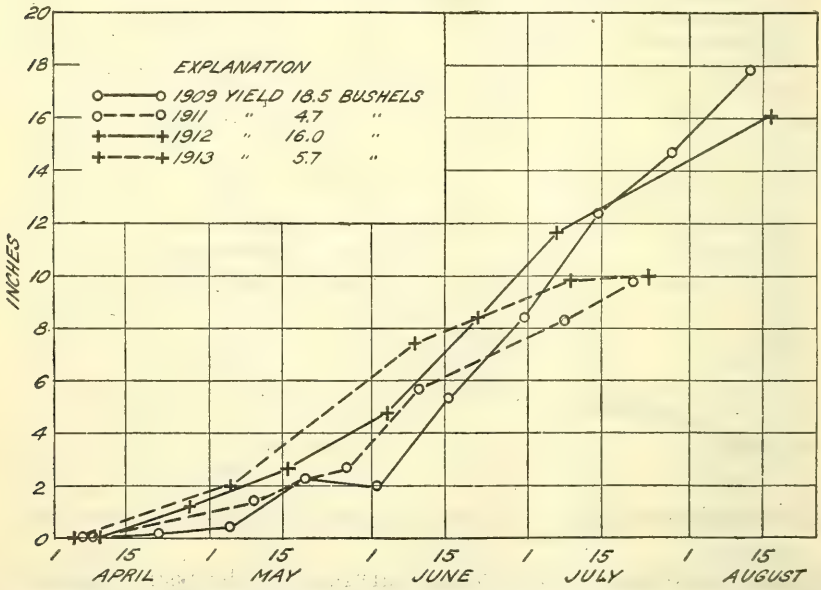

FIG. 5.—Diagram showing the use of water on wheat plat C or D at Akron, Colo., for the years 1909, 1911, 1912, and 1913.

little more water in the fallow plat C or D than in the continuously cropped plat A, and only a slightly higher yield was secured. In 1912 the continuously cropped plat A had more water and made a higher yield than the fallow plat C or D. In no year has there been enough additional water stored in fallow above that in continuously cropped land to carry a crop over any prolonged period of drought.

In general, the Akron curves represent a condition of water use from a soil of medium water-storage capacity. Comparison of the Akron curves with those of Dickinson shows the difference between the two stations in the quantity of water furnished to a crop through fallowing and the resulting increase in yields on fallow over those on continuously cropped land.

Figure 6 shows the water use on plat A at Amarillo, Tex., for the six-year period from 1911 to 1916, inclusive. The curves in this figure show why a high yield of wheat has never been obtained at this station. In three of the six years the wheat crop suffered for water from the time it commenced rapid growth until harvest. These three years all show a low rate of water use and a low yield. In the other three years there was enough moisture to enable the crop to make rapid growth for a time, but in each year the crop was short of water long before harvest and the yield was seriously reduced. In the history of these experiments there has not been a year at Amarillo when severe drought has not injured the crop before harvest, and consequently a high yield has never been produced. The reason for this lies largely in the high rate of water use from the time the crop begins rapid growth. It is evident that for the crop to have used

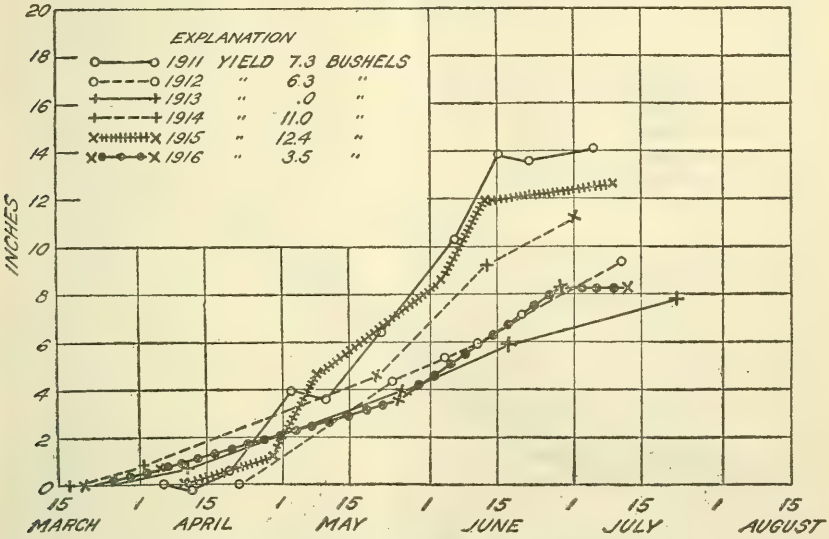

FIG. 6.—Diagram showing the use of water by the wheat crop on plat A at Amarillo, Tex., for the years from 1911 to 1916, inclusive.

water until its harvest date either in 1911 or in 1915 at the rate indicated during its early growth a supply of at least 22 inches would have been required. The average quantity of available water stored in the soil of plat A at the beginning of the crop season is less than 5 inches. In order for the wheat crop to grow to maturity without drought injury, a precipitation of at least 15 or 16 inches during its growth period would be necessary. The fact that such a precipitation is practically unknown gives at least one good reason why spring wheat is not adapted to that section of the Great Plains.

Figure 7 shows the water use on plat C or D for the same years shown in Figure 6 for plat A. The water use on the two plats is much the same, though enough stored water was present in plat C or D in most years to keep the crop growing a little longer before drought injury commenced. This resulted nearly every year in a higher yield for plat C or D. The only exception shown is the year 1915. In that year plat A used more water and produced a higher yield than plat C or D.

One fact evident at Amarillo is that the yield is correlated very little with the harvest date in the different years. This is probably because drought injury has been evident in all years. What little correlation exists in these curves is obscured by the fact that the date of the final sampling does not always coincide with that of harvest. For example, the wheat on plat A in 1913 was harvested July 1, but the first soil samples after harvest were taken on July 22.

In general, the soil-moisture results at Amarillo are subject to greater experimental error than those for any other station. In several years the samples were not taken frequently enough to show accurately the water use for the different stages in the growth of the wheat crop. The curves are presented because spring wheat grows better at this station than at any of the other stations so far south. The high rate of water use in good years when water is available

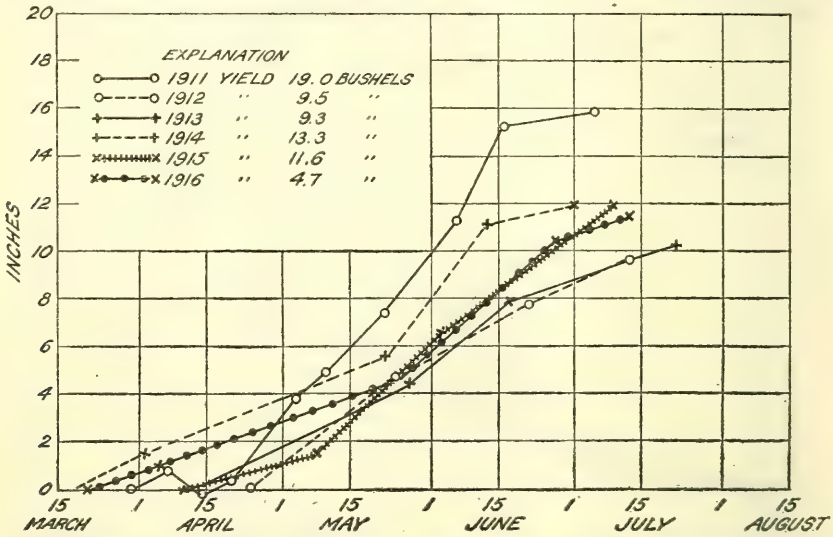

FIG. 7.—Diagram showing the use of water on wheat plat C or D at Amarillo, Tex., for the years from 1911 to 1916, inclusive.

and the evident drought injury in all years are the points most evident in the study of the results for the station.

The results of any one year or any one station are not conclusive in themselves, but those of all the years studied clearly point to certain conclusions in respect to water use.

Four types or general classes of seasons in respect to the use of water by the crop may be distinguished:

Seasons in which there is always sufficient water to meet the needs of the crop. This type of season is comparatively rare.

Seasons when the supply of water in the soil and from rains is great enough to carry a crop almost to maturity, but in which a forced ripening of the wheat takes place because of water depletion just before harvest. This type of season is common.

Seasons when drought conditions begin to affect the crop at or near heading time. In this case a forced ripening takes place, but there is in addition a wilting or firing of the grain for some time before harvest. This is a type of season that occurs frequently on the Great Plains.

Seasons in which the crop at no time has sufficient moisture for optimum growth, but in which by reason of its meager straw growth it may be enabled

to come to maturity and make a low yield through timely additions of moisture to the soil through rains. This type of season may occur in any portion of the Plains, but is more frequent in the southern than in the northern part.

To these might be added the very exceptional year of extreme drought in which the crop does not germinate or make any growth.

Each of these several types of seasons can be distinguished in the curves formed by the rate of the use of water during the season. Other conclusions drawn from the study of these data as a whole are as follows:

There is a loss of water from the soil before the crop has made growth enough to make its own demands heavy. This loss is small at the northern stations and increasingly greater farther south. It represents largely evaporation from the soil and is greater at the southern stations because of their higher temperatures and lower humidity.

Rapid growth of the wheat crop accompanied by a higher rate of use of water begins at approximately the same time each year at a given location. This date is earlier at the southern than at the northern stations, owing to the earlier development of the crop.

From the time the crop commences rapid growth until harvest the rate of the use of water continues nearly uniform as long as the crop does not suffer from drought. This is contrary to the general opinion, but this point was evident in all of the cumulative losses charted that were capable of yielding evidence on this point. In nearly every case where there was no suffering for water at any time during the season, the points established by the different dates of sampling between the time the crop commenced rapid growth and harvest lay in an approximately straight line.

The quantity of water used during periods of the same length was nearly the same, no matter whether the use was largely the precipitation for that period or whether it represented water stored in the soil. This indicates that the precipitation falling upon the soil during the growing season is as effective as if it were all added to the soil at a depth great enough to be beyond the reach of evaporation. The conclusion that all precipitation is as effective as if the amount of the precipitation were added to the quantity of water in the soil is open to criticism because of the fact that showers, particularly small ones falling on a dry soil, do not penetrate to a depth great enough to be available to crop roots. This is no doubt true, but, on the other hand, these showers are accompanied by lower temperatures and increased humidity. While none of the water falling in a small shower may be used by crops, the occurrence of the shower and its accompanying phenomena reduces the demand for water by the crop until the net result is somewhere near what it would have been had there been no shower but a quantity of water equivalent to it added directly to the soil.

The rate of the use of water by the crop when in full growth and neither suffering for lack of water nor previously compromised by a lack of water is determined by the environment due to geographical location, the environment due to season, and the extent of vegetative growth that constitutes it. This is the phase of the question that has been considered under the heading "Daily rate of the use of water while the crop is growing rapidly."

Any shortage of available water in the soil is accompanied by one of two phenomena in crop behavior and water use. If the crop is near maturity at the time the shortage occurs, a forced ripening takes place. The rate of water use may not be decreased noticeably during the last period, but ripening takes place at the time the soil moisture is exhausted. If drought begins to affect the crop earlier in the season, there is in addition to a forced ripening a period in which the crop either wilts or fires. During this period very little water is used, because the soil moisture is nearly exhausted. The crop may mature grain, but the yield is always seriously reduced.

The final yield of the wheat crop is determined more by the length of time it uses water rapidly than by the rate of use. In other words, the length of the line from the approximate time the crop commences to use water rapidly to the point where the water is exhausted and the rate of use becomes slower is nearly proportional to the yield. A high yield of wheat usually means not only a great quantity of water used during the season but a late harvest date as

well. In general, years in which high yields have been obtained show rates of use of water above the average, but the rate does not seem to be proportional to the size of the crop.

In considering the problem of water use, the ability of the wheat crop to adapt itself to the moisture conditions of the soil must be emphasized. Unless there is a great excess of precipitation over normal the crop will make growth enough or continue to grow long enough to utilize all the available moisture in the soil. In years when the growth is continued a long time the yield is always high unless adverse conditions, such as hail or rust, injure the crop. If at any stage during its growth wheat suffers from drought it seems to spend its last energy in producing seed, and if there is any possibility of doing so it will mature some grain even at the expense of its vegetative growth. In the extensive experiments with wheat in the Great Plains the available soil moisture has been entirely exhausted at harvest in 90 per cent of the cases studied.

QUANTITY OF WATER USED DURING THE GROWING SEASON.

The preceding studies have been concerned with the rate of the use of water. Under the present heading consideration will be given to the total quantity of water used during the growth of the crop under conditions that have actually existed at the points of experimentation during the several years for which data are available.

The total quantity differs in some cases from that reached at the final determination in the immediately preceding study in that the period may be somewhat shorter. That study began with the first determination in the spring, which was usually at seeding time, but may have been earlier. This served a useful purpose in fixing the rate of use, or loss as it might more properly be regarded, from the soil alone before the crop started growth. This period is an uncertain and variable one and likely to be much longer at the southern than at the northern stations. For the present study of the total quantity of water used by the crop it was considered that more comparable data would be obtained by limiting the period to the time the ground was occupied by the crop. The quantity of water used has, therefore, been calculated from a determination of soil moisture made about the time the wheat came up to a determination at harvest. In each case the determination selected as the first was the one made nearest to the time that the wheat came up. Its date varied from about April 15 to May 1 at the southern stations to about May 1 to May 10 at the northern stations.

To obtain the total loss of water during the growth of the crop the loss of water from the soil between the time the crop came up and harvest was determined and to this quantity was added the precipitation for the same period. The loss of water from the soil was determined in the same way as in the previous studies.

This study was made on plat A, which is continuously cropped to wheat.

The quantity of water used from the soil during the growing season, the precipitation for that period, and the total use of water for the growing season are shown in the first three figure columns of Table 3. The next three columns give the yield of grain per acre in

bushels, the yield of straw per acre in pounds, and the total yield per acre in pounds.

TABLE 3.—*Quantity of water used by the wheat crop during the growing season, yields of grain and straw, and water ratio on the continuously cropped wheat plat A for the years and stations specified.*

[The column headed "Ratio" shows the number of pounds of water used by the crop per pound of total yield.]

Station and year.	Water used.			Yield.			Ratio.
	From the soil.	Precipitation.	Total.	Grain.	Straw.	Total.	
	Inches.	*Inches.*	*Inches.*	*Bushels.*	*Pounds.*	*Pounds.*	
Assinniboine:							
1917	1.55	2.97	4.52	3.5	590	800	1,279
1919	1.00	3.11	4.11	1.5	200	290	3,208
Huntley:							
1913	4.44	4.12	8.56	16.0	1,740	2,700	718
1914	3.23	6.19	9.42	18.3	1,950	3,050	699
1915	2.00	10.45	12.45	24.5	2,250	3,720	758
Williston:							
1910	1.09	4.22	5.31	1.7	1,040	1,140	1,054
1911	.62	5.09	5.71	2.7	380	540	2,393
1912	2.89	9.08	11.97	25.2	1,860	3,370	804
1913	1.95	7.57	9.52	16.8	2,300	3,310	651
1914	2.19	11.11	13.30	23.8	1,910	3,340	901
1915	2.81	6.57	9.38	19.1	1,150	2,300	923
Dickinson:							
1909	−.97	16.30	15.33	26.8	2,110	3,720	933
1910	4.81	6.06	10.87	17.4	1,410	2,460	1,000
1911	1.32	5.53	6.85	5.7	700	1,040	1,491
1913	4.09	6.69	10.78	13.3	1,310	2,120	1,151
1915	−1.08	12.97	11.89	25.8	1,550	3,100	868
1917	3.12	3.62	6.74	5.5	610	940	1,623
Mandan:							
1915	−1.52	17.70	16.18	30.5	2,120	3,950	927
1916	4.64	7.86	12.50	19.2	2,100	3,250	871
1917	2.12	4.55	6.67	15.3	1,230	2,150	702
1918	3.44	5.97	9.41	12.7	1,390	2,150	991
1919	4.79	2.51	7.30	7.5	700	1,150	1,437
Edgeley:							
1907	2.90	6.60	9.50	4.1	1,950	2,200	977
1908	2.93	7.92	10.85	13.3	2,700	3,500	702
1909	2.51	10.52	13.03	28.3	2,900	4,600	641
1910	3.48	2.93	6.41	4.0	660	900	1,612
1911	4.96	5.54	10.50	.8	900	950	2,502
1912	2.83	12.94	15.77	35.0	3,100	5,200	686
1913	3.33	7.96	11.29	16.3	2,020	3,000	852
1914	2.84	8.20	11.04	11.3	2,970	3,650	685
1915	4.08	11.20	15.28	34.8	3,960	6,050	572
1917	3.58	5.52	9.10	8.3	1,150	1,650	1,248
Hettinger:							
1913	2.23	9.67	11.90	13.8	3,250	4,080	660
1917	2.04	4.67	6.71	5.2	.....	.....	.....
1919	1.30	3.02	4.32	0	0	0	.....
Belle Fourche:							
1909	2.53	11.74	14.27	23.8	3,050	4,480	721
1910	3.23	3.03	6.26	2.8	660	830	1,707
1912	2.09	4.31	6.40	0	1,300	1,300	1,114
1913	3.25	5.25	8.50	6.2	1,320	1,690	1,138
1914	1.40	5.25	6.65	4.0	1,180	1,420	1,060
1915	2.35	12.26	14.61	56.5	5,260	8,650	382
1916	2.66	7.34	10.00	10.6	1,360	2,000	1,132
1917	1.86	5.17	7.03	4.4	980	1,250	1,273
Ardmore:							
1915	3.43	15.16	18.59	49.2	3,450	6,400	657
1917	7.17	6.80	13.97	7.5	600	1,050	3,012
1918	2.51	11.11	13.62	27.7	2,090	3,750	822
1919	3.45	6.32	9.77	3.3	950	1,150	1,923
Archer:							
1914	3.71	3.32	7.03	6.8	940	1,350	1,179
1915	3.98	7.57	11.55	26.8	1,930	3,540	739
1916	1.70	7.34	9.04	2.3	680	820	2,495
1917	2.69	8.38	11.07	15.6	1,310	2,250	1,114
Scottsbluff:							
1911	3.57	3.85	7.42	.5	670	700	2,399
1912	3.26	4.81	8.07	8.7	980	1,500	1,218
1913	2.17	6.35	8.52	12.0	1,520	2,240	861
1917	2.81	8.14	10.95	9.2	970	1,520	1,631
1918	1.86	6.31	8.14	3.7	600	820	2,247

TABLE 3.—*Quantity of water used by the wheat crop, etc.*—Continued.

[The column headed "Ratio" shows the number of pounds of water used by the crop per pound of total yield.]

Station and year.	Water used.			Yield.			Ratio.
	From the soil.	Precipitation.	Total.	Grain.	Straw.	Total.	
	Inches.	*Inches.*	*Inches.*	*Bushels.*	*Pounds.*	*Pounds.*	
North Platte:							
1908	1.74	12.96	14.70	22.7	1,920	3,280	1,014
1909	3.24	13.56	16.80	23.0	3,060	4,440	856
1910	3.16	4.59	7.75	6.8	1,000	1,410	1,244
1911	−.08	1.55	1.47	0	0	0	.....
1912	5.74	3.32	9.06	12.8	1,790	2,560	801
1914	3.57	5.60	9.17	6.0	1,600	1,960	1,059
1915	−1.66	18.12	16.46	22.7	2,310	3,670	1,015
1916	3.26	6.72	9.98	17.2	2,440	3,470	651
1917	3.35	6.35	9.70	4.2	1,290	1,540	1,426
1919	3.56	10.66	14.22	15.5	3,370	4,300	749
Akron:							
1909	2.21	11.24	13.45	14.3	1,590	2,540	1,199
1911	1.26	3.94	5.20	2.9	480	660	1,783
1912	4.69	11.32	16.01	21.3	2,760	4,040	897
1913	.86	4.51	5.37	4.8	660	950	1,279
1914	4.71	5.50	10.21	22.2	2,530	3,860	599
1915	3.79	11.18	14.97	26.3	1,740	3,320	1,021
1916	2.76	5.04	7.80	9.3	1,140	1,700	1,039
Garden City:							
1909	.45	9.26	9.71	2.1	560	690	3,185
1911	.90	5.35	6.25	0	0	0	.....
1912	3.25	6.98	10.23	3.5	1,010	1,220	1,898
1914	5.15	4.12	9.27	1.5	1,290	1,380	1,520
1915	4.20	8.79	12.99	17.5	1,950	3,000	980
1916	2.44	2.24	4.68	0	0	0	.....
Dalhart:							
1909	−.36	5.61	5.25	0	0	0	.....
1910	2.41	7.05	9.46	0	0	0	.....
1911	.86	3.60	4.46	0	0	0	.....
1913	.83	4.03	4.86	0	0	0	.....
1914	6.23	10.41	16.64	7.8	1,280	1,750	2,152
Dalhart, new field:							
1914	4.23	10.41	14.64	8.4	690	1,200	2,761
1915	2.61	8.08	10.69	4.0	760	1,000	2,420
Amarillo:							
1909	−.97	8.68	7.71	0	0	0	.....
1911	2.39	11.01	13.40	7.3	1,070	1,510	2,009
1912	5.79	4.25	10.04	6.3	630	1,010	2,250
1915	7.66	4.17	11.83	12.4	1,800	2,550	1,050
1917	1.81	4.21	6.02	1.7	480	580	2,349
1918	1.11	3.73	4.84	0	0	0	.....
Tucumcari:							
1913	1.28	3.91	5.19	0	0	0	.....
1914	1.88	9.53	11.41	13.5	1,010	1,820	1,419
1915	6.95	4.80	11.75	5.6	685	1,020	2,607
1916	2.14	1.98	4.12	0	0	0	.....

Study of Table 3 shows that, at least so far as the individual stations are concerned, a definite relation exists between the total quantity of water used and the yield of grain, straw, and total weight per acre. This relation is not always consistent, but it must be borne in mind that when crops are subjected to the varying conditions that occur in the field a very close correlation is impossible, and any strong correlation, either positive or negative, is highly significant.

It will be noted from the study of all the stations that high yields are always associated with high water use. A high water use does not necessarily mean a high yield, because the crop may suffer either through poor distribution of rain or through some extreme climatic condition that limits the yield. On the other hand, a high yield necessitates a high use of water. Table 3 contains data on the use of water by 96 wheat crops. Twenty of these crops yielded more than 20 bushels of grain per acre. Only one of these consumed less than 11.5 inches of water. At Akron, Colo., in 1914, a yield of 22.2 bushels

was produced with a total water use of 10.21 inches. Plats on all sides of the one studied yielded much less, although their water content at the time of the determinations was nearly the same. An uneven drifting of snow was noted in the spring of this year, and it is possible that portions of this plat, which was in stubble, contained more water at the beginning of the season than the average shown by the soil samples taken.

The larger quantity of water needed at southern stations to produce a crop is clearly shown in this study of the total use of water at the different stations. For example, at Assinniboine, the northernmost station reported, small yields of grain and straw have been obtained from the use of 4.52 and 4.11 inches of water, respectively. At Hettinger, a little farther south, the use of 4.32 inches resulted in a total failure of both grain and straw. At Belle Fourche the use of between 6 and 7 inches of water has resulted in yields of grain ranging from nothing to 4 bushels per acre, and in yields of straw a little higher than those produced by the lesser quantities of water at Assinniboine. At Scottsbluff, Nebr., there has been no total failure, but yields approximating those at Assinniboine have required from 7 to 8 inches of water. At the four stations farthest south, Garden City, Dalhart, Amarillo, and Tucumcari, respectively, total failures of both grain and straw have resulted from the use of quantities of water varying from 4.12 to 9.46 inches. At none of these stations has a yield of grain or straw been secured when less than 6 inches of water has been used. Dalhart shows the poorest adaptation for wheat of any station under study. A yield of grain or straw has not yet been obtained there when less than 10 inches of water has been used.

In a few cases stations have matured a crop on less water than stations north of them, but the figures presented certainly justify the general statement that the quantity of water required to produce a crop of wheat depends upon geographical location and on the Great Plains increases with the distance south except as this is modified by altitude.

In order to obtain a mathematical expression for the relation that exists between the total use of water and the yield of wheat, a series of studies was made in which the total use of water was correlated with the yield of grain, yield of straw, and total weight of crop produced. All of these correlations have been determined by the product-moment method.

In these correlations the average yields for each station and the average water use for each station were used as bases for computing departures. As the quantity of water required to produce a crop is influenced by the location, this method of procedure was necessary in order to eliminate station differences. While this method may not be mathematically correct, it at least gives a result that can not be far wrong. It is the only method practicable, since there are only a few stations where there have been enough years to make individual-station correlations between yield and water use.

The results of the studies are as follows:

The correlation between the total quantity of water used and the yield of grain in bushels is 0.76, with a probable error of ± 0.03; the correlation between the total quantity of water used and the yield of straw per acre is 0.69, with a probable error of ± 0.03; and the correlation between the total quantity of water used and the total weight of grain and straw is 0.78, with a probable error of ± 0.03.

These figures represent a high degree of correlation and point out that the quantity of water used by the crop certainly exerts a preponderant influence on the yield. The fact that the quantity of water used correlates more closely with the total weight of crop produced than it does with the yield of either grain or straw is one that would be expected. It was not anticipated, however, that so close an agreement would exist between the two correlations of the yield of grain and water use and the yield of straw and water use as was shown by this study. It is, of course, necessary that there should be a yield of straw before a yield of grain can be produced, and it was thought probable that the total water use would correlate much more closely with the yield of straw than with the yield of grain or with the total weight. The fact that the three correlations agree very closely strikingly illustrates a statement previously made. This statement was that when affected by drought the wheat crop seems to spend its last energy in producing grain and that if there is any chance at all it will produce some yield of grain. This study indicates that a high yield of straw means a high yield of grain and that a low yield of straw means a low yield of grain. There have been a few cases when exceptionally favorable weather enabled wheat to fill so well that the yield of grain was out of proportion to the yield of straw. These years are very infrequent, and as a whole the yields of grain and of straw are nearly proportional.

It will be noted in Table 3 that in most years the precipitation has greatly exceeded the stored water used from the soil. In nearly every case a high precipitation means a high yield and a low precipitation a low yield. Very little relation is shown between the quantity of stored water used and the yield. There are two reasons why this is the case. In the first place the quantity of water stored in the soil is never enough to produce a good crop. Rainfall is necessary to supplement the soil moisture stored and a large quantity of stored moisture may be associated with a low rainfall, or vice versa. Another reason why the water used from the soil has little relation to the yield lies in the fact that the reduction of the soil water content is dependent upon the sufficiency or insufficiency of the rainfall. In years of heavy precipitation there may be an actual increase in the quantity of stored water in the soil at harvest over the quantity present at seeding time, and in these years a negative correlation between the water used from the soil and the yield is shown. This condition has been observed, but is very infrequent in dry farming.

That the stored water used from the soil actually plays an important part in the yield of the crop was shown by correlating precipitation with yield.

The correlation between the precipitation and the yield of grain was 0.74 ± 0.03, that between the precipitation and the yield of straw was 0.60 ± 0.04, and that between the precipitation and the total yield of grain and straw was 0.73 ± 0.03. These correlations are distinctly lower than those obtained in correlating the total water used and the yield. This makes it certain that though precipitation is the deciding factor in the yield of wheat the quantity of water stored in the soil in many cases is of great value in determining yields.

That the quantity of stored water is of importance in determining yields was shown by another study. Comparison of two plats each

year showed that the plat having the greater moisture content about May 1 gave the highest yield in 73 out of 93 cases. Very little correlation existed between the quantity of moisture stored and the yield in different years of the same plat. In other words, it was not possible to prove that 6 inches of stored water in the soil of a plat in one year was any more effectual in producing a good yield than 4 inches of water might be in another year. The precipitation was the deciding factor. However, when two plats were compared for the same year the plat having the greater quantity of stored water present was fairly certain to produce the higher yield. A plat with 6 inches of stored water available was almost certain to produce a higher yield of grain than one having 4 inches of water. While the

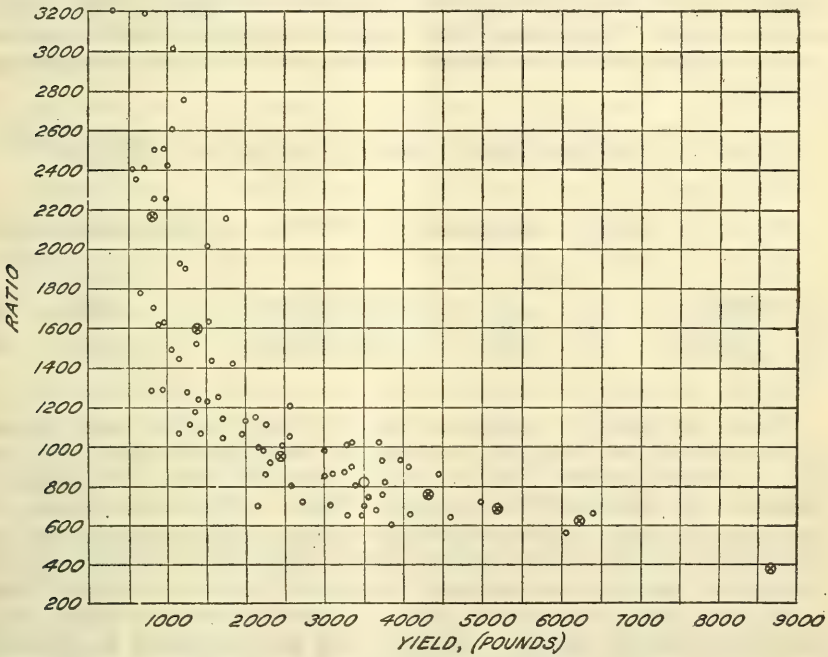

FIG. 8.—Diagram showing the total yield and ratio of pounds of water used to pounds of yield of wheat. The small circles are from data in Table 3. The crosses within circles show the averages by 1,000-pound yield groups, as given in Table 4.

precipitation for the growing season is the deciding factor in wheat production, the quantity of stored water supplementing the rainfall has a decided bearing upon the yield of the crop.

To facilitate comparison of these results with those obtained in controlled studies of water requirement, the ratio of the total water use to the total weight of crop harvested has been calculated and is given in the last column of Table 3. The correlation of the yield with these ratios is shown by dots in Figure 8. The yields of grain and straw in pounds per acre are charted as abscissa and the pounds of water per pound of crop as ordinates. The dots tend to arrange themselves in a curve showing increasing efficiency in the use of water with increasing yield. A reason for this is brought out under the succeeding heading, where it is shown that the consumption of a certain quantity of water is necessary before any yield is produced

and that yields increase in proportion to the quantity of water consumed above this. For those yields under 2,000 pounds per acre there is a wide variation in the ratio of water used to yield. This is not unexpected, as such yields do not represent normal growth throughout the season or in many cases for any part of the season. A further cause of divergence is the wide range of conditions from the northern to the southern Plains covered by the data. There is a much closer grouping for the yields above 2,000 pounds per acre, as these are more nearly expressive of the requirements of normal growth.

The yields have been averaged in groups of 1,000 pounds and the corresponding averages of the respective ratios determined. These averages are given in Table 4 and shown in Figure 8 by crosses within circles. No attempt has been made to determine a mathematical expression of the relation evidenced in the data comprising Figure 8.

TABLE 4.—*Ratios and total yields of wheat shown in Table 3 arranged in yield groups of 1,000 pounds and expressed as averages of such groups.*

Yield group.	Number in group.	Yield average.	Ratio average.	Yield group.	Number in group.	Yield average.	Ratio average.
		Pounds.				*Pounds.*	
1 to 1,000 pounds	15	793	2,165	5,001 to 6,000 pounds	1	5,200	686
1,001 to 2,000 pounds	26	1,413	1,588	6,001 to 7,000 pounds	2	6,225	615
2,001 to 3,000 pounds	14	2,444	951	7,001 to 8,000 pounds	0	----------	----------
3,001 to 4,000 pounds	18	3,492	814	8,001 to 9,000 pounds	1	8,650	382
4,001 to 5,000 pounds	6	4,323	754				

While the ratios of water to yield obtained in this work range higher than those obtained in controlled water-requirement studies, such as those reported by Briggs and Shantz,[2] there are sufficient reasons why this should be the case. These field studies include all loss from the soil itself which was excluded in physiological studies. Our yields are relatively lighter, because they do not include an undetermined residue that remains as stubble in the field plats from which the crop is harvested with the self-binder but which was included with the crop by clipping close to the ground in pot cultures. This difference, however, is partly offset by the difference between dry and air-dry material. Maximum efficiency was obtained in pot cultures by constantly maintaining an optimum water content, a condition which is the exception rather than the rule in the field. The results all show that the efficiency of water is increased (the water requirement reduced) by the maintenance of conditions that favor maximum production.

CORRELATION BETWEEN THE USE OF WATER AND THE YIELD AT INDIVIDUAL STATIONS.

A study was made of the correlation between water use and yield at two stations—Edgeley, N. Dak., and North Platte, Nebr. These stations were not selected because of their location but because results for more years were available at these stations than at any of

[2] Briggs, L. J., and Shantz, H. L. The water requirement of plants. U. S. Dept. Agr., Bureau of Plant Industry Bul. 284, 49 pp., 2 fig., 11 pl. 1913.

the others. Even at these stations the number of years was far too small for a reliable correlation to be made, but it was thought that any close relation that existed would be shown.

At Edgeley the results for 10 years on plat A were used. The correlation between the total water used and the yield of grain was 0.90 ± 0.04. Since the other studies made showed little difference in relations between the yield of grain and the total weight, only the one correlation was made. Figure 9 shows the use of water and the yield of the plat each year. In this figure the axis of ordinates represents the water used in inches and the axis of abscissas the yield in bushels.

It can be easily seen that the points established in the different years group themselves along a line that does not have its origin at zero. The use of several inches of water seems to be necessary before

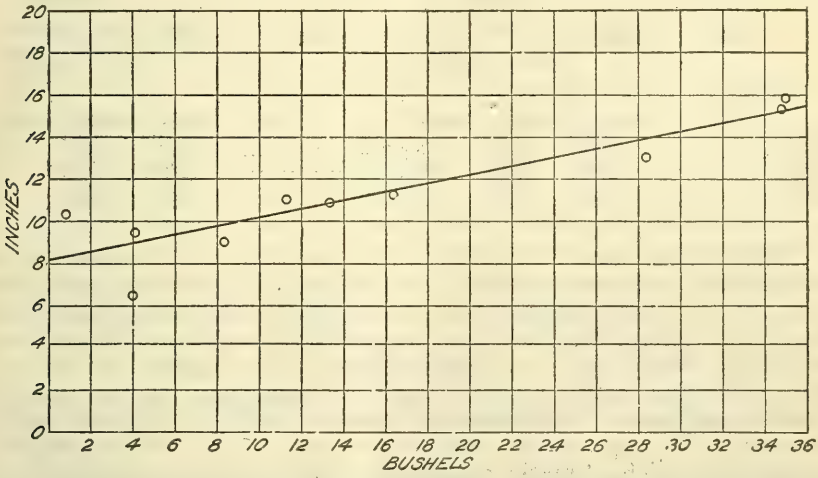

FIG. 9.—Diagram showing the yield of wheat and use of water on plat A at Edgeley, N. Dak., for 10 years. The line is drawn from the linear-regression equation $M = 8.16 + 0.20\ e$.

any yield is produced. After enough water to produce a yield has been used there appears to be a linear relation between the water and the yield. The starting point and slope of a line representing the relation of water use and yield were determined by the linear-regression formula:

$$M = \bar{y} - (\sqrt{xy}\ \sigma x \div \sigma y\ \bar{x}) + \sqrt{xy}\ \sigma x \div \sigma y\ e.$$

Determined in this way, the resulting linear-regression equation was M equals 8.16 plus 0.20 *e*.

The application of this equation is made as follows: Eight and sixteen one-hundredths inches represents the quantity of water necessary before a yield of grain is secured. Starting from that point, each succeeding increase of 0.20 inch of water should result in an increase of 1 bushel in yield. The line in Figure 9 is the line established by this equation.

It is not contended that 8.16 inches represents the quantity of water necessary before a yield is secured. It is simply a point determined by 10 years' results that indicate the average zero point

for these years. It may be either above or below the point that might be established if the results of a larger number of years were available.

The accuracy of the linear-regression equation in expressing the relation between water use and yield at this station is shown in Table 5. This table gives the total water used in inches, the actual yield in bushels per acre, and the yield in bushels per acre as calculated from the water use by the linear-regression equation.

TABLE 5.—*Actual and computed yields of wheat per acre on plat A at Edgeley, N. Dak., in the 10 years stated.*

[The quantity of water used during the growing season as stated in the table forms the basis of the computed yield as calculated by the linear-regression equation $M=8.16+0.20\,e$.]

Year.	Water used.	Yield.		Year.	Water used.	Yield.	
		Actual.	Computed.			Actual.	Computed.
	Inches.	*Bushels.*	*Bushels.*		*Inches.*	*Bushels.*	*Bushels.*
1907	9.50	4.1	6.7	1912	15.77	35.0	38.1
1908	10.85	13.3	13.5	1913	11.29	16.3	15.7
1909	13.03	28.3	24.4	1914	11.04	11.3	14.4
1910	6.41	4.0	0	1915	15.28	34.8	35.6
1911	10.50	.8	11.7	1917	9.10	8.3	4.7

Table 5 shows how accurately in this case the yield of wheat can be determined from the quantity of water used. In only two years, 1910 and 1911, did the computed yield differ greatly from the actual yield. In 1910 a yield of 4 bushels per acre resulted from a use of water considerably below the 8.16 inches theoretically supposed to show a zero yield, and in 1911 a yield of only 0.8 bushel per acre was secured with a total use of 10.5 inches of water. In 1911 hot winds badly damaged the crop and seriously reduced the yield. This represents a year in which climatic conditions overbalanced the quantity of water used in determining the yield. The closeness of the computed yield to the actual yield at this station is probably due in part to the fact that at Edgeley crops feed to a depth of only about 2 feet. The inclusion of only 2 feet of soil no doubt makes the size of the experimental error in the determination of water used at the station small.

At North Platte the data of nine years are available. The correlation between the total water use and yield is 0.85 ± 0.06. The year 1911 is eliminated because of the zero yield. This failure was the result of a use of only 1.47 inches of water. Since there might still have been a failure had more water been used, this year does not establish any definite point, and consequently is not included in making the correlation or in determining the linear-regression equation.

The linear-regression equation determined is $M=6.22+0.40\,e$. Figure 10 shows the points established by water use and yield in the several years, together with the line established by the linear-regression equation.

At North Platte the points established by the water use and yield each year do not lie as close to the line established by the linear-regression equation as those at Edgeley. They do, however, group themselves near enough to the line to indicate that it is not far wrong.

Comparison of Figure 10 with Figure 9 shows some interesting facts. In the first place, the quantity of water calculated as necessary before a yield above zero would be produced is lower at North Platte than at Edgeley in spite of the fact that it is located much farther south. The reason for this is not known, unless it is because of the shallowness of the Edgeley soil, which makes even a short drought seriously reduce the yield.

The point most in evidence is this: Each bushel of yield at Edgeley requires 0.2 inch of water above the minimum, and each bushel yield at North Platte requires 0.4 inch of water above the minimum. A greater mass of data to work from would undoubtedly change the

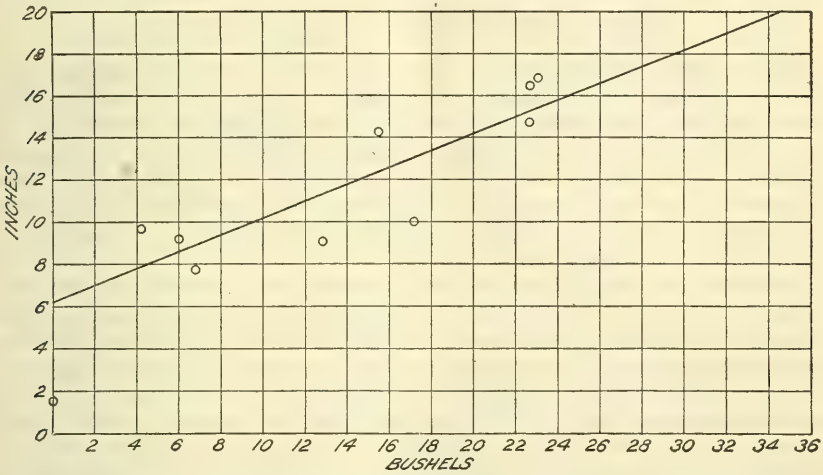

FIG. 10.—Diagram showing the yield of wheat and use of water on plat A at North Platte, Nebr., for 10 years. The line is drawn from the linear-regression equation $M=6.22+0.40\ e$.

slope of these lines somewhat, but it is apparent that the quantity of water necessary to produce each successive bushel of yield is much higher at North Platte than at Edgeley.

The linear-regression formula has been used in computing yields at North Platte. Table 6 gives for plat A at North Platte the water use in inches, the actual yield, and the yield computed by the linear-regression equation.

TABLE 6.—*Actual and computed yields of wheat per acre on plat A at North Platte, Nebr., in the nine years stated.*

[The quantity of water used during the growing season as stated in the table forms the basis of the computed yield as calculated by the linear-regression equation $M=6.22+0.40\ e$.]

Year.	Water used.	Yield.		Year.	Water used.	Yield.	
		Actual.	Computed.			Actual.	Computed.
	Inches.	*Bushels.*	*Bushels.*		*Inches.*	*Bushels.*	*Bushels.*
1908	14.70	22.7	21.2	1915	16.46	22.7	25.6
1909	16.80	23.0	26.5	1916	9.98	17.2	9.4
1910	7.75	6.8	3.8	1917	9.70	4.2	8.7
1912	9.06	12.8	7.1	1919	14.22	15.5	20.0
1914	9.17	6.0	7.4				

It has not been possible to compute yields by the linear-regression formula as closely at North Platte as at Edgeley. This may be because there is a greater experimental error at North Platte than at Edgeley, for it is necessary to include the soil to a depth of 6 feet in the samplings. It is probable, however, that the real reason lies in the fact that North Platte lies in a section not so well adapted to spring wheat as Edgeley. Extreme conditions of temperature that affect wheat adversely are much more common. The lack of the same correlation at North Platte as at Edgeley may and probably does indicate the greater proportional effect that conditions other than the quantity of water used have upon the yield.

GENERAL DISCUSSION OF THE RESULTS.

Physiological studies of the use of soil water by crop plants have determined the use of water by the plants alone. Such studies have been of utmost importance in their contribution to knowledge of the relation between the plant and its environment and between different groups of plants. As such studies are made under conditions that permit the escape of no water except through the plant they measure the maximum possibilities of growth or production from a given quantity of water.

The present study attempts to measure the rate of use and the quantities of water used under the complex of conditions that environ the crop in the field. The data available for study are of such a character that only approximations for given conditions and averages can be arrived at. Indeed, the problem itself is not of a nature to permit exact determinations. If the methods were so refined and the work so replicated as to approach exactness in the results for any given condition, the complex of this condition might never be duplicated. To furnish usable information marking a distinct advance in the knowledge of the subject it is not necessary that determinations of the rate of use or the quantity of water used be exact. It is not of primary importance to know whether a crop uses water at the rate of 0.15 or 0.16 inch per day, but it is important to know whether the rate be 0.15, 0.30, 0.60 inch, or even more per day. The wider variations and greater ranges are of primary agricultural importance, and within such ranges the approximations of rates and quantities arrived at meet the requirements made of them.

Many writers draw erroneous conclusions of the possibilities of a given rainfall by not recognizing the fact that yield is not directly proportional to the quantity of water used. A common presentation is that if a given number of inches of water produces a certain size of crop then double the quantity of water will produce twice that much. The data here presented show that such calculations may be very misleading. An analogy may be drawn from the animal world to illustrate the source of error in such calculations. In feeding live stock it is well recognized that a certain quantity of feed is consumed as a living ration. This quantity alone results in zero growth, and some quantity in addition to this must be supplied if there is to be an increment of growth. The results of the present study show that in the field the consumption of a certain quantity of water is necessary before any yield of grain is produced. Or, stated in another way, the consumption of a certain quantity of water only results in a zero yield. This quantity may vary in the Great Plains from perhaps 4 to 10

inches for wheat, depending upon the season and the locality. Yields have a direct relation to the quantity of water consumed above this minimum. In general, the quantity required as a minimum to any production as well as the quantity above this minimum required for each unit increment of yield increases with change of location from north to south.

The study now made shows the incessant and heavy demand of the crop for water from the time it commences growth until it matures. The yield depends upon this demand being met uninterruptedly. When the water to meet this demand is not available in the soil, the rate of use is necessarily decreased. Such decrease always compromises the yield. Fortunately for the success of agriculture, death of the plant from a shortage of water is a very indefinite and long-delayed occurrence. When field crops suffer distress, they sacrifice vegetative growth to seed production and only cease their efforts after they have exhausted all available water and produced more or less seed. Under conditions where the water supply is normally insufficient or very seldom more than sufficient to meet the possible maximum demands of the crop under full possible development, it is consequently the normal condition for the available soil water to be exhausted when the crop matures. If death of the crop were as sudden a phenomenon as the exhaustion of soil water, the percentage of crop failures would be much higher than it is.

Abbreviated column headings used in the tables and repeated in the text have distinguished between water used from the soil and watter supplied by precipitation. Actually, of course, the entire use is from the soil, and the division is between the quantity already in the soil at the beginning of the period studied and the precipitation by which this quantity is replenished from time to time. The available water in the soil is the reservoir from which the crop draws. Its quantity may fluctuate from time to time as the precipitation is greater or less than the current needs of the crop. So long as it is not depleted to the point of exhaustion the crop appears able to maintain its normal rate of use indicated by an uninterrupted curve. When depletion reaches the critical point marking the division between available and nonavailable water, the rate of use is interrupted and the crop suffers. Precipitation replenishes the supply, and the use of water is resumed. A sufficiently detailed study of this condition would show intermittently low and high rates of use. In the present study these are averaged together for considerable periods of time. The result of this is to show a low rate of use for the period. When such a condition exists early in the season the vegetative growth is either reduced or not developed, and the rate of use when water is available is thus reduced. This is the condition reflected in the curves that show a low rate of use and a small quantity of water used. This is the condition referred to by such statements in the text as "The crop suffered from drought throughout the season."

Maximum possibilities can be realized only when the water supply is at all times adequate to permit use at an uninterrupted rate. The present determinations of this rate show that at the northern stations the wheat crop in the field requires an inch of water every five or six days. At the southern stations the demand rises to an inch of water every four or even every three days.

This rapid consumption of water, considered in connection with the normal rainfall, shows why it is so unusual for water to accumulate during this period and why the water in storage at its beginning is so generally exhausted. To furnish a surplus in addition to meeting the needs of the crop, a rainfall much greater than the normal would be required. Of all the years and stations studied there has been only one year at one station when the water content of the soil at harvest time was higher than at the commencement of rapid growth.

Knowledge of the rate of use and of the quantity of water used is of fundamental importance in forecasting at any time during the period of growth the probable production from the rainfall that is to be expected, or the quantity of water that must be received to realize a given production, or the quantity that will result in very small yields or complete failure.

After certain preliminary investigations and determinations on a soil it is possible to determine quickly, within 24 to 48 hours, the quantity of available water that it contains. Knowing the approximate daily rate of use, it is a simple calculation to determine how long a period of drought can be endured without damage. It is equally easy to calculate the rate at which water must be supplied in order to bring the crop to maturity without damage or to calculate the probable results of any given rate or quantity of rainfall. The probabilities of a given rainfall and the probable range of rainfall for most points are known or may be easily calculated. Precipitation, of course, can not be foretold except as to its probabilities and the limits that are likely to encompass it.

Practical application of such forecasting has been made at a number of the field stations of the Office of Dry-Land Agriculture Investigations by members of the office staff for several years with very gratifying results. Such predictions may even be advanced to the preceding fall, but the longer the period involved the greater is the chance of unfavorable conditions being corrected.

CONCLUSIONS.

The crop has a supply of water measured by the available water in the soil at the time growth begins plus the precipitation during the period of growth. Under dry-farming conditions the two combined are seldom more than sufficient to meet the needs of the crop.

For any period during the growth of the crop the rate at which water is used is practically independent of whether it is obtained by reducing the water content of the soil or is supplied by precipitation during the period.

Water is lost from the soil before seeding or before the crop commences growth, and at an increasingly rapid rate as vegetation develops until, at about the time tillering is completed or just before the crop begins to shoot, it reaches a rate that is maintained practically constant until maturity, provided there is always water available to maintain this rate.

Maximum yields are dependent upon the uninterrupted maintenance of this rate throughout the period of growth. Yields are compromised to the extent that the normal rate is interrupted or reduced. If the water supply is short in the early season, vegetative growth may be reduced and the rate continue low. Interrup-

tion and insufficiency of water supply later may result in firing and forced maturity. Failure of the water supply near the end of the growth period may result in forced maturity without marked reduction in the rate of use before maturity. Type curves showing the rate of use for the entire season are presented for representative years and localities.

The daily rate of use of water by a wheat crop is dependent upon climatic environment and the quantity of vegetation that composes it. As climatic environment is determined by geographical location, the rate of use of water by a unit quantity of crop is consequently primarily dependent upon geographical location and secondarily upon seasonal conditions. Within the limits that these overlap, either one or the other may dominate.

The normal rate of the use of water by the wheat crop during its period of rapid growth has been determined to average from about 0.15 to about 0.20 inch per day at stations in the northern Great Plains, the rate depending upon the quantity of crop as influenced by cultural practices. This rate is increased from 50 to 60 per cent at stations in the southern Great Plains.

The total consumption of water by the crop shows a high degree of correlation with the yield produced by it. A high yield necessitates a high use of water. Of 93 crops studied in this connection only one yield of more than 20 bushels per acre was produced from the use of less than 11.5 inches of water. On the other hand, a high use of water may not necessarily result in a high yield, because of failure of the water supply toward the end of the growing season, or because unfavorable conditions other than water supply may intervene to prevent the potential yield from being realized. This lowers the correlation.

The data studied indicate that for any locality within the Great Plains the relation between the yield and the water consumed during the growth of the crop is a linear one, but the origin of the line is not zero. The consumption of a certain minimum quantity of water is necessary before any yield above zero is realized. Each unit increase of water consumed above this minimum appears to result in a unit increment of yield. Both the minimum quantity required and the quantity required for each unit increment of yield depend upon the climatic environment of the season and in the average upon the geographical location. The minimum quantity of water necessary to the harvest of any grain has varied from about 4 inches at the northern stations to as high as 10 inches at the southern stations. Tentative formulas are presented for Edgeley, N. Dak., and North Platte, Nebr., by which to calculate the yield from the water consumption.

The quantity of available water that may be stored in the soil is not sufficient of itself to meet the needs of the crop. The quantity of available water in the soil can be quickly determined at any time. Knowing the daily rate of use and the time necessary to mature the crop or the total quantity of water required for a given production, the probable yield from a given precipitation during the remainder of the growing season or the precipitation necessary to produce a given yield can be calculated. This method of forecasting yields has obvious limitations, but it affords a better basis of approximation than has heretofore been available.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 1005

Contribution from the Bureau of Soils
MILTON WHITNEY, Chief

Washington, D. C. ▼ April 24, 1922

SOILS OF EASTERN VIRGINIA AND THEIR USES FOR TRUCK CROP PRODUCTION.

By J. A. Bonsteel, *Scientist in Soil Survey.*

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INTRODUCTION.

Two distinct and separate localities in eastern Virginia have been developed for the production of special vegetable crops for shipment to outside markets and commonly known as truck crops.

The first and oldest of these, the Norfolk district, lies to the south of the James River, eastward from the vicinity of Suffolk to the Atlantic Ocean. The other, the Eastern Shore district, of more recent development, occupies a large proportion of Accomac and Northampton, the two Eastern Shore counties of Virginia. The two districts are separated by the lower stretches of Chesapeake Bay and present certain distinctive natural aspects. They possess the common characteristics of being located in close proximity to tidewater, of lying at low elevations which range from sea level to extreme altitudes of about 50 feet above tide with the greater part of the total land surface at elevations of 15 to 40 feet, of being well located with respect to shipping facilities, and of experiencing a long growing season.

Since the two districts differ in detail in regard to certain of these factors, it is necessary to describe them separately.

THE NORFOLK TRUCKING DISTRICT.

LOCATION.

The Norfolk trucking district is located chiefly within the northern parts of Isle of Wight, Nansemond, Norfolk, and Princess Anne Counties, Va. Even within these counties the production of truck crops is distinctly localized to positions near tidewater, extending from the Lynnhaven River on the east to the Nansemond River on the west. By far the greater part of the land used for the growing of truck crops and strawberries lies north of a line drawn from Princess Anne courthouse to Suffolk, Va., and east of a line drawn thence northward to the James River, near Smithfield. Small areas producing truck crops are also found in James City, York, Warwick, and Elizabeth City Counties, but these lie across the James River and outside the limits of the Norfolk district in its more restricted sense.

Only a small proportion of the total land area of the counties of eastern Virginia lying south of the James River and Chesapeake Bay is given to truck crop production. It is impossible to state with exactness the actual acreage devoted to this form of agriculture, as the area varies from year to year and certain duplications in cropping prevent the making of a precise estimate of the land thus employed.

The climatic conditions in the vicinity of Norfolk permit the growing of a succession of crops during the year, and the same land is frequently used for the growing of two or more crops within the same year. In consequence the total acreage of vegetables will undoubtedly exceed by many acres the total area devoted to truck crop production. The winter areas of spinach and kale are duplications of acreages used for the growing of spring truck crops. Similarly, certain crops are extensively interplanted, as in the case of beans and peas with strawberries, peas with cucumbers, potatoes with newly set beds of strawberries, and other less frequent combinations. (See Pl. I, figs. 1 and 2.)

It is probable that some 5,000 acres of duplication should thus be allowed for and that the total land area used for truck crop production in the Norfolk district annually during recent years is about 50,000 acres.

It is evident, therefore, that only a small part of the area included in the district is actually used for truck crop production. The reasons for this limitation are local conditions of soil texture, drainage, transportation facilities, and minor climatic variations.

CLIMATE.

The Norfolk trucking district constitutes the most northern area where it is the common practice to produce vegetable crops throughout the year for shipment to more northern markets. Ability to follow this practice is dependent upon local climatic conditions to a considerable degree. The district lies at a low elevation contiguous to large areas of tidewater and approximately in latitude 36° 30′ to latitude 37° north.

According to the records of the United States Weather Bureau for the Norfolk station, the region has an annual mean precipitation of 49.29 inches, well distributed throughout the year, and the mean annual temperature is 59.2° F. There is an average annual snowfall of 9.4 inches, which occurs almost entirely in December, January, and February. The average date of the first killing frost in the fall is November 12 and of the last in spring March 27. Although killing frosts have occurred as early as October 15 and as late as April 26, in general a frost-free season of about 230 days would seem to be indicated. The winter conditions of temperature are such also that certain classes of vegetables, notably spinach, kale, and cabbage, may be grown throughout that season.

PRODUCTION, TRANSPORTATION, AND MARKETS.

Shipments of truck crops grown in this district are made to all the larger northern and northeastern cities. The district is served by several trunk lines of railroads and by half a dozen lines of steamboats which carry truck crops to Washington, Baltimore, Philadelphia, New York, Boston, and other northern cities. Locally the produce is collected for shipment by power boats, owned and operated by the different farmers or by others, by local steam and electric railroads, and to some extent through wagon haul to the shipping point. (See Pl. II, figs. 1 and 2.)

Two truck growers' associations manage the shipments of the greater part of the produce, and the figures for the total amounts of shipments for a series of years have been compiled by Prof. T. C. Johnson, director of the Virginia Truck Experiment Station. Table I shows the amount of these shipments from 1909 to 1914, inclusive. The figures are given for the trucking year, which terminates with August 31.

TABLE I.—*Annual shipments of truck crops, Norfolk district, Va., 1909 to 1914.*

Crop.		1909–10	1910–11	1911–12	1912–13	1913–14
Potatoes	barrels	934,592	587,141	1,051,651	946,550	817,972
Spinach	do	559,032	598,260	652,758	760,619	890,061
Kale	do	325,835	281,308	438,239	437,075	498,483
Cabbage	do	382,200	298,400	380,844	379,657	369,622
Sweet potatoes	do	70,463	52,003	68,145	41,406	47,805
Strawberries	60-quart crates	165,665	121,482	221,826	106,063	153,118
Beans	baskets	301,116	240,101	394,384	320,695	249,101
Peas	do	120,050	108,815	81,364	69,817	117,540
	barrels	1,167	7,013	8,241	3,124	2,093
Cucumbers	do	124,501	92,853	68,947	111,339	122,193
	baskets	38,656	41,886	46,945	65,994	41,109
Radishes	do	107,959	112,481	112,902	132,577	134,107
Lettuce	do	64,335	57,566	57,320	57,838	71,260
Beets	crates	12,739	8,878	7,492	13,884	16,928
Egg plant	do	29,418	19,900	27,113	34,389	16,735
Cantaloupes	do	35,354	44,284	14,190	27,113	19,525
	barrels	296	51	17	.....	1,080
Tomatoes	crates	26,326	16,054	8,951	1,376	2,195
Cauliflower	baskets	8,106	12,366	5,242	16,953	19,540
Squash	barrels	10,825	12,156	5,096	14,688	8,681

In addition to these crops there were shipped appreciable quantities of asparagus, onions, peppers, parsley, carrots, turnips, and dandelion. Small shipments were also made of artichokes, cress, endive, okra, leeks, fennel, and celery.

PERIODS OF SHIPMENT OF TRUCK CROPS.

The continuous production of truck crops in the Norfolk district throughout the year and the realtive volume of production in the different seasons are indicated by the periods of normal shipment for the different important crops.

Irish potatoes are shipped from early in June to the middle or latter part of July. Usually the greater volume of shipment lies between June 10 and June 30.

Strawberries are shipped largely from the last of April to the middle of May, with shipments continuing until the end of that month.

Cabbage is shipped from about April 1 to the 10th of June.

Cucumbers, grown under sash, are shipped throughout the month of May, while the field-grown crop is marketed chiefly during June and July.

Radishes are shipped from early April to the 1st of July.

Lettuce is marketed during March and April, in the spring, and again from the latter part of September well into December, in the fall.

Egg plant is coming to be an important summer crop, marketed in the latter part of June, throughout July, and into August.

Cantaloupes are shipped from the latter part of June until a little past the middle of August.

Beets are shipped from the 20th of April until July.

Snap beans are shipped in the spring from about June to July 20 and in the fall during October and the early part of November.

Peas are marketed in the spring from the end of April to early June and in the fall from about September 20 to October 25.

Tomatoes from hothouses are marketed from just before Christmas throughout the winter months, and the field crop from the middle of June until the end of October.

Spinach is shipped from the last days of October throughout the winter months and until about the middle of April.

Kale is shipped from the 1st of November until the middle of April.

Sweet potatoes are shipped as they are dug, from the latter part of August to the end of October and from storage throughout the winter and early spring months well into April.

Aside from the hothouse and cold frame products, it is evident that the greater part of the shipments for the Norfolk district occur from the middle of April to the middle of August. Some crops are marketed until November, but the distinctly winter truck crops—spinach and kale—and such crops as are grown under hothouse conditions or may be stored constitute the bulk of the shipments from November 1 until well into April.

These facts, in conjunction with the figures giving the volume of shipment for the different crops, indicate that the Norfolk district is marked by year-round activity in trucking, but that the greater acreage and greater volume of business arise from the production of early spring and summer crops.

AGRICULTURAL POPULATION.

The business of truck crop production is chiefly in the hands of the native-born population of eastern Virginia and of a few individuals who have been attracted from other parts of the United States. The truck farms are operated either by their owners, by hired managers, or by tenants. Practically all of the labor is performed by colored laborers, including men, women, and the larger children, the women and children being employed at the lighter tasks at certain seasons of the year. A part of the labor is hired for extended periods (by the month or year), but a considerable volume of transient labor is also employed during the period of harvesting and marketing the principal crops.

PHYSICAL FEATURES.

The entire Norfolk trucking district lies within the Atlantic Coastal Plain. It is a region of low relief, no elevations greater than 30 feet above tide level occurring within Norfolk and Princess Anne Counties. Portions of Isle of Wight and Nansemond Counties rise to somewhat greater elevations.

If a line be drawn along the Nansemond River southward through Suffolk to the North Carolina boundary, it will be found that practically all of the territory lying to the east of this line lies at an

altitude ranging from 10 to 30 feet above tide level. The surface is very flat and all of the southwestern part of the section is occupied by the Dismal Swamp. The eastern and northern parts lying along the Nansemond River, James River, Elizabeth River and its branches, the Chesapeake Bay, and the Atlantic Ocean, occur at altitudes from tide level up to 25 or 30 feet. Although the surface is flat, the deep tidal indentations constitute natural drainage ways and a great part of the upland surface is fairly well drained under natural conditions.

It is a rather marked feature of the general surface of the section that the highest elevations of the upland occur along the northern border, frequently adjacent to the larger estuaries, and that the slight slope of the surface is toward the south and southeast.

Thus the outer rim of the section has the best natural drainage both because of its proximity to the larger estuaries and the most pronounced drainage ways and because of slightly greater elevation above tide level than the lands more remote from tide water. This fact undoubtedly accounts to some degree for the greater development of trucking along tidewater than in interior localities.

The district is drained almost exclusively through the deeply indented and numerous tidal estuaries which penetrate the region to a depth of 5 to 10 miles from the actual coast line. These estuaries are usually bordered by steep slopes, and the upland rises to elevations of 10 to 15 feet almost directly from water level. The drainage of the level to slightly sloping uplands finds its way to the major streams through shallow and frequently poorly defined channels. The interstream areas are so flat that drainage is rather poorly established in areas more remote from the tidal channels.

Since drainage strongly influences the distribution of cropping, this fact is of considerable importance in determining the localization of crop production, especially of truck crops. Poorly drained lands remain in forest. Those of moderate natural drainage are used for the growing of staple farm crops. Only the best drained and warmest lands are utilized for the production of truck crops. In some cases tile underdrainage and in many cases open ditches are employed to improve local drainage conditions on the truck farms. Yet the preferred lands for truck-crop production are those which possess the best natural drainage.

SOILS.

All of the soils of the Norfolk district are derived from unconsolidated materials of the Coastal Plain region, ranging in texture from coarse gravelly sandy deposits or dune sand on the one hand to finer textured loams and silt loams on the other. Soils which consist chiefly of finely divided mineral matter cover all of the marginal areas, but soils with which are mingled varying amounts of dead

and decaying organic matter are extensively developed in and around the margins of the Dismal Swamp. In the latter area there are extensive areas which consist of peat or of living moss bogs.

Since there is a rather wide divergence in the degree to which different areas have been drained and subjected to weathering of the surface materials, there is quite a divergence in the soil series or groups within the region. Added to this is a marked diversity of soil textures. From these two facts it becomes possible to distinguish different soil series and divide them into several soil types.

Sassafras series.—The surface soils of the Sassafras series are distinguished by their brownish color and usually rather friable structure. The subsoils are reddish yellow to brownish red in color, friable to compact in structure, and typically rest at some depth on beds of coarse sand and gravel or of fine gravel. Their drainage is excellent. Although of rather small extent in the Norfolk district they constitute soils sought after for truck-crop production. The Sassafras coarse sandy loam, fine sandy loam, and small areas of the loam occur within the district, usually along ridges or near the major drainage ways.

Norfolk series.—The soils of the Norfolk series are gray to yellowish gray in color and usually friable in structure. The subsoil is pale yellow and normally somewhat more compact than the surface soil. At a depth ranging from 5 or 6 inches to 24 or 30 inches there is usually present a rather compact sandy clay subsoil which is decidedly retentive of moisture. Drainage is normally fair to good. This series is the dominant one in the Norfolk trucking district. It is represented by the gravelly sandy loam, gravelly loam, fine sand, coarse sandy loam, fine sandy loam, loam, and silt loam.

Keyport series.—The Keyport series includes soils similar in origin to those of the Norfolk series, but not quite so well drained under natural conditions. The surface soils are grayish brown in color and the subsoils mottled gray and yellow with some reddish-brown stains. The deep subsoil is frequently mottled gray and yellow. It is sometimes water soaked and in most places somewhat plastic. The Keyport fine sandy loam is the only type of this series encountered in the Norfolk area within the trucking district.

Suffolk series.—The surface soils of the Suffolk series are gray or grayish brown in color and rather compact under tillage conditions. The subsoils are pale gray and frequently saturated at a depth varying from 5 inches to 2 feet. They occupy broad, level tracts, away from the principal streams or are found in depressed areas, associated with other soils. Drainage is naturally defective, but can be improved sufficiently for the production of some crops by the use of open ditches. The Suffolk fine sandy loam, loam, and gravelly loam occur in the district.

Portsmouth series.—The types included in the Portsmouth series are characterized by dark-brown to black surface soils and by gray to slightly mottled gray and yellow subsoils. In some places the deeper subsoil is almost white. The surface soils are normally high in organic matter. The Portsmouth soils represent swampy accumulations. The series is poorly drained in its natural condition and occupies depressions, broad level areas, and stream margins. It is the common soil condition of the marginal portions of the Dismal Swamp. Cultivation to quite a variety of crops is possible where drainage has been adequately established.

Swamp.—The Swamp areas of the region consist of the Dismal Swamp and numerous small tracts of undrained land. The soil material consists chiefly of an accumulation of organic matter with varying proportions of mineral matter, the latter having been washed or blown into the swampy areas. The Swamp is largely forested, but considerable tracts of once swampy land have been cleared and drained, both within the limits of the Dismal Swamp and around its margins. In almost all cases such tracts are found to possess soils of the Portsmouth series, although small areas of peat are also encountered.

Dunesand.—Along the coast line, particularly in the vicinity of Cape Henry, there are great accumulations of medium to fine textured wind-blown sand. Part of this material has been heaped up into dunes 15 to 70 feet in elevation, while other large tracts consist of low ridges and intervening hollows or plains of wind-swept sand. Many of these areas are covered with a thick vegetation of live oak and pitch pine; others are bare of vegetation.

Such a wide diversity of drainage and soil conditions naturally gives rise to a considerable difference in the degree to which different localities are utilized for agriculture and to a discriminating occupation of different soil types for use in the intensive business of truck crop production.

DETAILED SOIL AND CROP MAPS.

During the fall of 1915 and the summer of 1916 surveys were made in the vicinity of Churchland and Diamond Springs, Va., to show the relationships that exist between the soils of the Norfolk trucking district and the distribution of the more important crops grown. The Churchland area is fairly representative of the trucking area along the Western Branch of the Elizabeth River, extending thence to the Nansemond River. The Diamond Springs area represents the conditions that exist in the northern part of Princess Anne County, where truck crops are also extensively grown.

The Churchland Area.

A detailed soil and crop map was made in the vicinity of Churchland in the summer of 1916. It covers approximately 1,180 acres of intensively tilled land. The area included lies along the Western Branch of Elizabeth River. It is bounded on the eastern, southern, and western borders by tidewater, while its northern boundary is an arbitrary line. The surface of the upland is nearly level, rising scarcely more than 15 feet above tide level at its greatest elevation. Along the tidewater margins there is usually a steep slope from the general surface down to water level. This narrow border presents practically the only steeply sloping land within the area. Slight depressions and small streamways exist within the upland, but the greater part of the surface is so nearly level that intensive cultivation is carried on over practically every acre.

This area includes the territory within which truck farming has been carried on from the beginning of specialized farming in the Norfolk district and is one of the most intensively cultivated areas in the district.

The detailed soil and crop map of the Churchland area was made on the scale of 6 inches to the mile, or 1 inch to 880 feet.[1] Upon this map the different soils are plotted in great detail and the boundaries of each field or crop area are shown. From this map it is possible to ascertain the actual crop occupation of each soil type at the time of the survey, to measure the total areas of each type occupied by the different crops, and to compute the relative importance of the different soils for the growing of each crop.

In order that both spring and fall conditions might be shown in this region of year-round farming, crop maps were made in June and late in August.

SOILS.

It was found that even within this small area there are seven distinct soil types or conditions, exclusive of tide marsh, the area of which is negligible, and of the sloping areas along the shores, which are not used for any agricultural purpose.

Sassafras fine sandy loam.—The surface soil of the Sassafras fine sandy loam, to a depth of 9 inches, is a friable, brown loamy fine sand. This is underlain to a depth of about 18 inches by a yellow, loamy fine sand, which grades downward into a rather stiff, reddish-brown loam.

The surface of this type is nearly level or only slightly sloping. The type lies adjacent to tidewater and is usually bounded on the outer margins by rather steep slopes. Toward the interior it grades

[1] For publication the several maps have been reduced to a uniform scale of 1 inch to 1,000 feet. These maps will be found at the end of this bulletin.

imperceptibly into the Norfolk fine sandy loam, usually without any appreciable change in level or of slope. It possesses better natural drainage than any other soil in the area and consequently is highly prized for truck crop production. Practically all of it is cleared and used for cropping or for the location of dwellings and grounds.

Norfolk fine sandy loam.—The surface soil of the Norfolk fine sandy loam, to a depth of 9 inches, is a brown to grayish-brown loamy fine sand. This is underlain to a depth of 18 to 20 inches by a yellow fine sand, only slightly coherent. The deeper subsoil, from 20 inches to 36 inches or more, is a yellow to brownish-yellow, stiff sandy loam. The surface of the type is level or but gently sloping, natural drainage conditions are good, and the land is highly esteemed for truck crop production. Owing to its greater extent, not only in this area but in the entire district, it is more important than the Sassafras fine sandy loam for the production of truck crops. Both soils are recognized as excelling any other in the district for this type of farming.

Keyport fine sandy loam.—The surface soil of the Keyport fine sandy loam consists of about 8 inches of grayish-brown fine sandy loam, somewhat coherent and tending to form crusts and clods. The upper 14 inches of the subsoil is a mealy yellow loam to fine sandy loam, and the deeper subsoil a heavy yellow loam, somewhat mottled with gray below a depth of 24 inches.

The surface of this soil is level and somewhat depressed below the adjacent soils. Natural drainage is fairly good but has been supplemented in the Churchland area by extensive systems of tile underdrainage. (Pl. III, fig. 1.)

The Keyport fine sandy loam is chiefly used for the growing of truck crops and is almost completely under tillage for that purpose.

Suffolk fine sandy loam.—The surface soil of the Suffolk fine sandy loam, to a depth of about 9 inches, is a gray to brownish-gray fine sandy loam. It is usually quite coherent and loamy. The subsoil, from 9 to 18 inches, is a pale yellow or gray loam. The deeper subsoil to 36 inches or more is in most places a gray fine sand, slightly loamy and sometimes mottled with yellow iron stains. The material in the lower part is frequently decidedly wet.

The type occupies level to depressed areas in the upland and occurs along some poorly marked streamways. It is poorly drained in its natural condition, but has been generally underdrained and rendered available for truck crop production in the Churchland area. (Pl. III, fig. 2.)

Norfolk fine sand.—The surface soil of the Norfolk fine sand, to a depth of 8 inches, is a yellowish-brown or yellow fine sand, slightly loamy. The subsoil, which extends to a depth of 36 inches or more, without change, is a yellow fine sand.

This soil is of small extent either in the Churchland area or in the general region. It occurs on slight ridges near the shore line and probably represents small accumulations of wind-blown sand. In this locality it is excessively drained.

Loamy sand.—In certain of the tilled fields erosion has carried quantities of fine sand from the higher elevations down the slopes toward the shallow streamways. These slopes are subject to both the accumulation and removal of sandy material from time to time. They present a varied surface soil which is for the most part a yellow fine sand 12 to 20 inches deep. At greater depths this may be loamy or the fine sand may extend to a depth of 36 inches or more.

This material occurs only in narrow bands and usually is cultivated in conjunction with more extensive and important upland types.

Portsmouth loam.—The surface soil of the Portsmouth loam to a depth of 12 inches or more is a dark brown loam. The subsoil is usually a gray, loamy fine sand or a gray fine sand to a depth of more than 36 inches. The type occupies small depressions in the upland and at stream heads. Near the centers of such hollows the brown loamy surface soil sometimes has a depth of 24 inches or even more. The type represents accumulations of organic matter and of soil washed from the uplands. In its natural condition it is poorly drained, but some tracts in the Churchland area have been improved by tile underdraining. The areas are so small that no distinctive cropping is usually adopted.

Steeply sloping land.—Between the upland and the tidewater inlets the land slopes rather steeply down. Such narrow areas have been left in timber to a considerable extent. The slopes are not usually occupied by any definite type of soil, but consist chiefly of somewhat sandy wash from the upland, overlying the more loamy deeper strata of the region.

Tidal marsh.—At the heads of the small tidal indentations there are some small areas of tidal marsh. These have not been drained and are not used agriculturally.

It is notable that practically all of the soils of this area posess a fine sandy loam surface soil. The essential differences between the several types appear most markedly in the subsoils and consist chiefly in differences in the texture and coloration of the deeper subsoil.

The dark-brown to reddish-brown color of the subsoil of the Sassafras fine sandy loam indicates good natural drainage conditions and the thorough aeration and oxidation of the material.

The yellow color of the Norfolk fine sandy loam indicates good drainage and aeration, though possibly not so complete as in the case of the former type.

The gray or mottled coloration of the other types indicates that natural drainage conditions have been more or less imperfect and this has resulted in incomplete aeration and oxidation.

In the Churchland area these variations in natural drainage conditions have been modified in some degree by the installation of tile drains, but the natural conditions of drainage have not become completely changed. (See Pl. III, figs. 1 and 2.)

The distribution of the different soil types in the Churchland area is also significant of the same facts with regard to drainage. The Sassafras and Norfolk fine sandy loams occupy the marginal positions, where drainage is effected directly by seepage to the steeper marginal slopes and by run-off through the deeper streamways. The Keyport and Suffolk fine sandy loams occupy interior positions, where the drainage of water away from the subsoil is not so complete and where the minor streams are not so deeply cut nor effective. The Portsmouth loam is found along streams or at stream heads.

These major facts of drainage illustrate upon a small scale and for limited areas the general conditions throughout the Norfolk district. The best drained lands are generally found nearest the tidewater channels and at the crests of the more elevated ridges. Positions remote from these channels and especially areas which lie on the almost level uplands between the major streamways are less well drained.

USES OF SOILS.

In order that the details of soil occupation might be determined, the completed soil and crop maps of each detailed survey were measured and the acreage of each form of occupation was computed for each soil type.

Since the production of truck crops continues throughout the year in both the Churchland and Diamond Springs areas and since significant methods of cropping are different at different seasons in the Onley area, Eastern Shore district, crop maps were made at two seasons for each of the three Virginia areas.

In the case of the Churchland area the figures shown for the June crop map represent the cropping conditions when the marketing of truck crops is at its height. Some areas of crops, marketed in the early spring, are not shown. The figures given for the August map represent the summer and early fall crop areas of the Churchland area.

Tables II and III show the proportion of total area and of the area of each soil type occupied by the various crops and groups of crops in June and in August, 1916.

TABLE II.—*Proportion of total area and of the area of each soil type occupied by various crops and groups of crops, Churchland area, June, 1916.*

Crop and group of crops.	All soils.		Sassafras fine sandy loam.		Norfolk fine sandy loam.		Keyport fine sandy loam.	
	Acres.	Per cent.	Acres.	Per cent.	Acres.	Per cent.	Acres.	Per cent.
General farm crops	9.8	0.9	.....	.....	9.2	1.9	0.6	0.3
Soy beans	7.0	.6	.....	.....	6.4	1.3	.6	.3
Corn	2.8	.3	.....	.....	2.8	.6	.....	.....
Truck crops	942.1	87.1	154.7	81.3	438.3	89.8	201.0	95.5
Potatoes	614.5	56.8	91.1	47.9	299.0	61.2	123.4	58.6
Cabbage	142.7	13.3	18.7	9.8	48.8	10.0	48.3	23.0
Beans	52.1	4.8	2.1	1.1	34.4	7.0	7.5	3.6
Cucumbers	15.1	4.8	20.8	10.9	.2	2.4	11.2	7.3
Cucumbers and peas	36.7				11.6		4.1	
Strawberries	45.6	4.6	3.2	3.1	29.9	6.4	5.6	2.6
Strawberries and beans	4.5		2.8		1.3			
Beets	15.6	1.4	10.5	5.5	4.9	1.0	.....	.....
Cauliflower	11.0	1.0	2.8	1.5	7.3	1.5	.9	.4
Miscellaneous vegetables	4.3	.4	2.7	1.5	.9	.2	.....	.....
No annual crops	129.3	12.0	35.5	18.7	40.8	8.3	8.8	4.2
Forest	44.5	4.2	1.6	.8	.8	.2	6.9	3.3
Gardens and grounds	62.8	5.8	27.9	14.7	26.9	5.5	1.9	.9
No crops	20.9	1.9	6.0	3.1	13.1	2.6	.....	.....
Swamp	1.1	.1	.....	.....	.....	.....	.....	.....
Grand total	1,081.2	100.0	190.2	100.0	488.3	100.0	210.4	100.0

Crop and group of crops.	Suffolk fine sandy loam.		Portsmouth loam.		Norfolk fine sand.		Loamy sand.	
	Acres.	Per cent.	Acres.	Per cent.	Acres.	Per cent.	Acres.	Per cent.
Truck crops	107.5	73.7	9.9	83.9	6.4	68.8	24.3	95.7
Potatoes	71.8	49.2	5.2	44.1	6.4	68.8	17.6	69.3
Cabbage	20.6	14.1	2.4	20.3	.....	.....	3.9	15.3
Beans	6.2	4.3	.4	3.4	.....	.....	1.5	5.9
Cucumbers	3.7	.....	.....	.....	.....	.....	.....	.....
Cucumbers and peas	.2	2.6	.....	.....	.....	.....	.....	.....
Strawberries	5.0	.....	1.9	.....	.....	.....	.....	.....
Strawberries and beans	.....	3.4	.....	16.1	.....	.....	.4	1.6
Beets	.....	.....	.....	.....	.....	.....	.2	.8
Miscellaneous vegetables	.....	.....	.....	.....	.....	.....	.7	2.8
No annual crops	38.3	26.3	1.9	16.1	2.9	31.2	1.1	4.3
Forest	34.4	23.6	.8	6.8	.....	.....	.....	.....
Gardens and grounds	2.8	2.0	.....	.....	2.2	23.7	1.1	4.3
No crops	1.1	.7	.....	.....	.7	7.5	.....	.....
Swamp	.....	.....	1.1	9.3	.....	.....	.....	.....
Grand total	145.8	100.0	11.8	100.0	9.3	100.0	25.4	100.0

Rough, broken land, chiefly in forest, 69.4 acres.
Tidal marsh, 27.3 acres.

TABLE III.—*Proportion of total area and of the area of each soil type occupied by various crops and groups of crops, Churchland area, August, 1916.*

Crop and group of crops.	All soils.		Sassafras fine sandy loam.		Norfolk fine sandy loam.		Keyport fine sandy loam.	
	Acres.	Per cent.	Acres.	Per cent.	Acres.	Per cent.	Acres.	Per cent.
General farm crops	601.5	55.6	76.6	40.2	270.4	55.1	138.6	66.2
Hay[1]	312.4	28.9	39.1	20.5	153.1	31.2	73.8	35.3
Corn	163.3	15.1	27.3	14.3	71.8	14.6	36.3	17.3
Corn and soy beans	11.7	1.1			1.1	.2	10.4	5.0
Corn and cowpeas	89.0	8.2	8.0	4.2	25.1	5.1	15.1	7.2
Cowpeas	22.7	2.1	2.2	1.2	19.3	3.9	.6	.3
Millet	2.4	.2					2.4	1.1
Truck crops	333.8	30.8	75.7	39.7	170.4	34.7	61.4	29.4
Kale	157.0	14.5	32.7	17.2	84.1	17.1	27.9	13.3
Spinach	70.8	6.5	36.1	18.9	26.0	5.3	7.4	3.6
Potatoes	60.3	5.6			36.5	7.4	17.3	8.3
Strawberries	40.5	3.7	6.5	3.4	22.9	4.7	5.6	2.7
Beans	3.2	.3					3.2	1.5
Sweet potatoes	2.0	.2	.4	.2	.9	.2		
No annual crop	146.9	13.5	38.2	20.0	49.9	10.2	9.2	4.4
Forest	44.5	4.1	1.6	.8	.8	.2	6.9	3.3
Gardens and grounds	58.4	5.4	27.9	14.6	22.5	4.6	1.9	.9
No crop	42.9	3.9	8.7	4.6	26.6	5.4	.4	.2
Swamp	1.1	.1						
Grand total	1,082.2	99.9	190.5	99.9	490.7	100.0	209.2	100.0

Crop and group of crops.	Suffolk fine sandy loam.		Portsmouth loam.		Norfolk fine sand.		Loamy sand.	
	Acres.	Per cent.	Acres.	Per cent.	Acres.	Per cent.	Acres.	Per cent.
General farm crops	88.6	60.8	7.9	66.4	4.7	50.5	14.7	59.0
Hay[1]	37.8	26.0	2.1	17.6			6.5	26.1
Corn	17.3	11.8	3.4	28.6	3.7	39.8	3.5	14.1
Corn and soy beans							.2	.8
Corn and cowpeas	33.5	23.0	2.4	20.2	.6	6.4	4.3	17.2
Cowpeas					.4	4.3	.2	.8
Truck crops	15.1	10.4	2.1	17.7			9.1	36.6
Kale	8.4	5.7	.2	1.7			3.7	14.9
Spinach	.7	.5					.6	2.4
Potatoes	2.8	2.0					3.7	14.9
Strawberries	3.2	2.2	1.9	16.0			.4	1.6
Sweet potatoes							.7	2.8
No annual crop	42.0	28.8	1.9	16.0	4.6	49.5	1.1	4.4
Forest	34.4	23.6	.8	6.7				
Gardens and grounds	2.8	2.0			2.2	23.7	1.1	4.4
No crop	4.8	3.2			2.4	25.8		
Swamp			1.1	9.3				
Grand total	145.7	100.0	11.9	100.1	9.3	100.0	24.9	100.0

[1] Volunteer hay, following a spring truck crop.

Rough, broken land, chiefly in forest, 69.4 acres.
Tidal marsh, 27.3 acres.

SOIL AND CROP ACREAGES FOR JUNE.

The crop map for June indicates that a total area of 942.1 acres or 87.1 per cent of the total area mapped is given to the growing of truck crops. In fact only 9.8 acres, or less than 1 per cent of the area, is in general farm crops. The remainder of the area, comprising 129.3 acres of upland, consists of land occupied for gardens and grounds, 62.8 acres; of forest, 44.5 acres; and of land not cropped and land classed as swamp, 22 acres.

The percentages established by this table for "All soils" constitute a standard of comparison for the individual soils. The Sassafras fine sandy loam carries no general farm crops, and is more extensively occupied for home grounds than any other of the types. This arises from its well drained and accessible position near the water fronts and decreases to some extent its showing as a highly prized truck soil.

The Norfolk fine sandy loam carries the only appreciable area of general farm crops, amounting only to 9.2 acres, or less than 2.0 per cent of the total area of the type. It is occupied by 438.3 acres of truck crops, or 89.8 per cent of its area, and has only a small area not occupied by annual crops.

The Keyport fine sandy loam is chiefly occupied by truck crops and is avoided for gardens and grounds. It includes a small but appreciable area of forested land.

The Suffolk fine sandy loam is marked by a high percentage of forested land. The greater part of the forest remaining in the locality is on this type, amounting to 34.4 acres, or 23.6 per cent of its entire area. (See Pl. IV, figs. 1 and 2.) The remainder is used chiefly for truck crop production.

The soils of smaller extent within the area do not show any particularly significant forms of occupation and their area is too small to justify any definite conclusions concerning their specific uses.

It should be emphasized that both the Keyport and the Suffolk fine sandy loam are utilized to a totally disproportionate extent in the Churchland area, because of the fact that the underdrainage of these soils has been decidedly improved by the installation of tile drains, rendering them capable of truck crop production. In the general region they are more commonly used for the growing of forage crops or in the more remote locations have been left in forest.

Of the spring truck crops Irish potatoes occupy the largest area. The Irish Cobbler is grown for the early market and the total acreage amounts to 614.5 acres, or 56.8 per cent of the total upland area. (See Pl. V, figs. 1 and 2.) They constitute over 65 per cent of the total acreage devoted to spring truck crops.

Cabbage constitutes the crop next in rank with regard to acreage. A total of 142.7 acres, or 13.3 per cent of the total area, is given to this crop. The cabbage crop is set during the winter and very early spring and harvested as an early spring crop. (See Pl. VI, fig. 1.)

Beans, either grown alone or interplanted with strawberries, and cucumbers and strawberries are grown to almost an equal extent in this section. The other truck crops are of minor importance.

The distribution of the various spring truck crops on the different soil types shows a slight excess of Irish potatoes on the Norfolk fine

sandy loam and the Keyport fine sandy loam, the former type leading in total acreage and in percentage of acreage for the section. This fact accords well with the general observations with respect to potato production in the Norfolk district. The Norfolk fine sandy loam, both because of its greater extent and of its peculiar suitability of texture and drainage, is the most important Irish potato soil in the district.

With regard to cabbage production, both the Sassafras fine sandy loam and the Norfolk fine sandy loam fall somewhat behind the average for the areas mapped; the area upon the Keyport fine sandy loam is decidedly larger than the general average, and that upon the Suffolk fine sandy loam is somewhat above the general average.

The proportionate area in snap beans is higher on the Norfolk fine sandy loam than on any other type.

Cucumbers are somewhat concentrated upon the Sassafras and Keyport fine sandy loams, the former leading.

Strawberries are chiefly encountered on the Norfolk fine sandy loam, while garden peas are grown chiefly as an interplanted crop with cucumbers on the Sassafras fine sandy loam.

SOIL AND CROP ACREAGES FOR AUGUST.

The soil and crop map showing conditions in the latter part of August indicates a totally different distribution of cropping from that recording conditions in June. In August the spring truck crops have been harvested and marketed and their places taken either by forage crops or by truck crops capable of making a full growth and of being harvested during the winter months.

The general farm crops cover, in August, 601.5 acres, or 55.6 per cent of the total upland area. The truck crops, including strawberries, which occupy the land during the year, covered but 333.8 acres, or 30.8 per cent of the area. The area not occupied by annual crops is slightly greater than in June, owing to the fact that certain fields have not been replanted.

The standards for the area are again established by the percentages for "All soils." It appears that the soils which do not possess the most complete natural drainage bear a somewhat high proportion of forage crops, as in the case of the Keyport and Suffolk fine sandy loams, which carry, respectively, 66.2 and 60.8 per cent of general farm crops, while the Sassafras and Norfolk fine sandy loams carry but 40.2 and 55.1 per cent of their areas in such crops. The latter figure is approximately the normal for the area, as would be expected from the dominating extent of the type.

Among the fall and winter truck crops the largest acreage is given to kale in the Churchland area. It occupies a total area of 157 acres or nearly one-half of the total in truck crops. The Sassafras and

S-8356

FIG. 1.—INTERPLANTING OF POTATOES AND STRAWBERRIES ON NORFOLK COARSE SANDY LOAM, DIAMOND SPRINGS, VA.

S-8244

FIG. 2.—INTERPLANTING OF SNAPBEANS AND STRAWBERRIES ON NORFOLK FINE SANDY LOAM, NEAR CHURCHLAND, VA.

S-8256

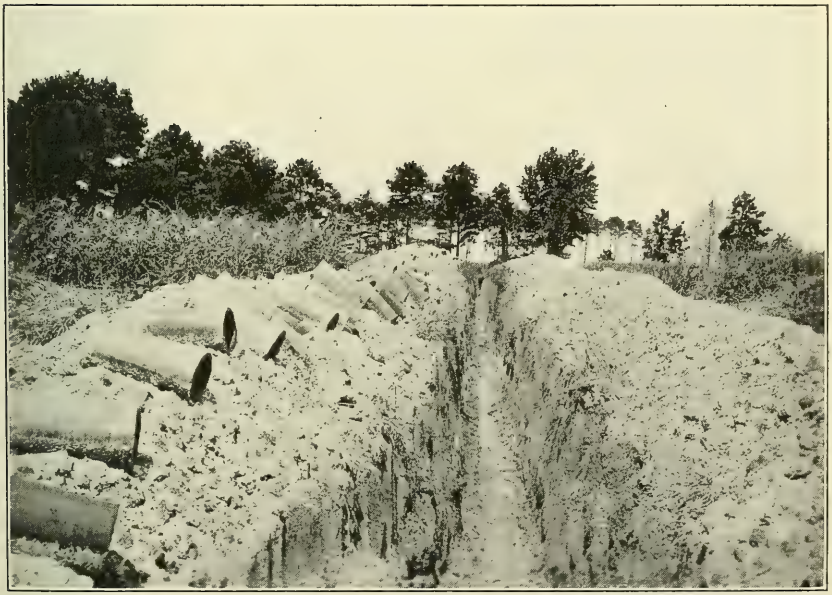
FIG. 1.—TRUCK CROPS TAKEN BY POWER BOAT TO THE SHIPPING POINT AT NORFOLK. WESTERN BRANCH.

S-8222

FIG. 2.—POTATOES, SHIPPED BY RAIL AT LOCAL STATIONS, NEAR CHURCHLAND, VA.

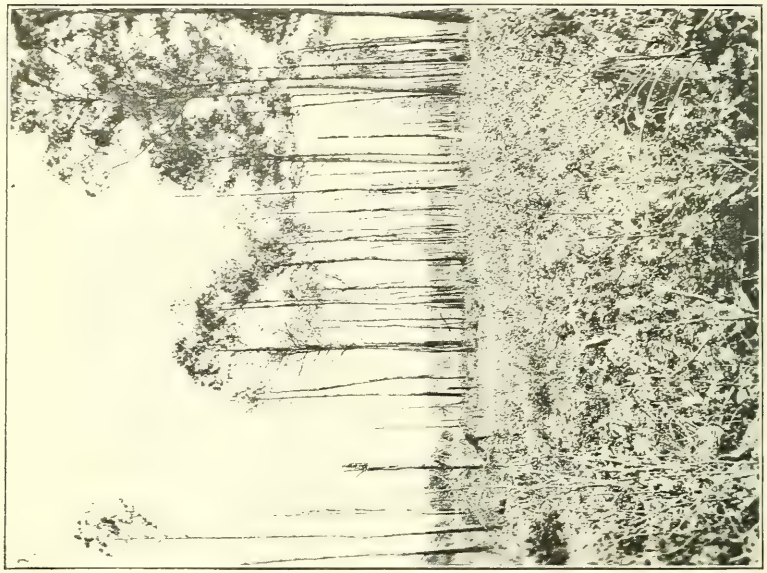
S-8458

FIG. 1.—INTAKES FOR TILE DRAINAGE ON KEYPORT FINE SANDY LOAM, CHURCHLAND AREA, VA.



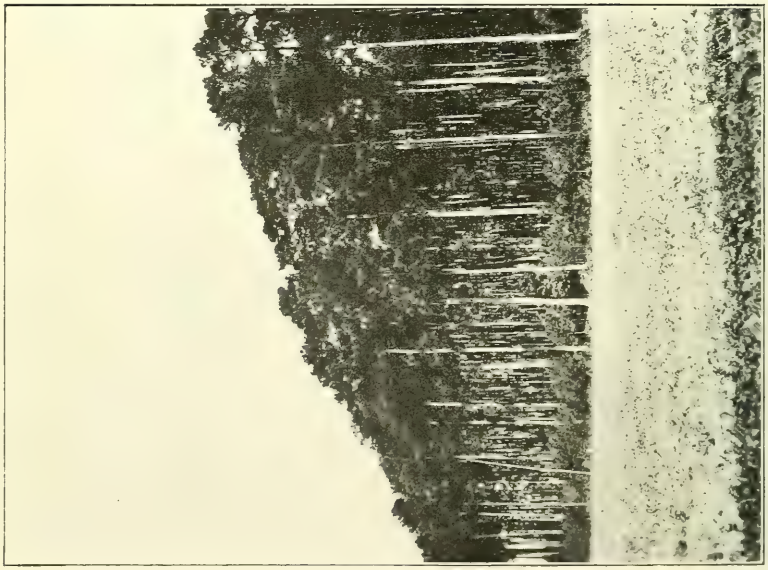
S-8486

FIG. 2.—TILE DRAINAGE ON KEYPORT AND SUFFOLK FINE SANDY LOAMS, NEAR CHURCHLAND, VA.



S-8423

FIG. 2.—CUT-OVER TIMBER ON NORFOLK LOAM, NEAR DIAMOND SPRINGS, VA.



S-8514

FIG. 1.—PINE-FOREST ON SUFFOLK FINE SANDY LOAM, NEAR CHURCHLAND, VA.

S-8516

FIG. 1.—EARLY POTATOES, IRISH COBBLER, ON NORFOLK FINE SANDY LOAM, NEAR CHURCHLAND, VA.

S-8261

FIG. 2.—HARVESTING EARLY POTATOES IN THE NORFOLK TRUCKING DISTRICT.

Norfolk fine sandy loams are the chosen soils for this crop, although the Keyport fine sandy loam is likewise important in its production.

Spinach is second in acreage to kale, covering 70.8 acres, or 6.5 per cent of the total upland area. Its production is decidedly localized upon the Sassafras fine sandy loam, the best drained soil in the area. Only the Norfolk fine sandy loam bears any large additional acreage.

The fall crop of Irish potatoes, the "Peachblow" variety, occupies 60.3 acres, or 5.6 per cent of the area. This fall crop is chiefly upon the Norfolk and Keyport fine sandy loams.

The acreage in strawberries is slightly less than in June because of the plowing out of old beds. The fall acreage is found chiefly upon the Norfolk and Keyport fine sandy loams.

Only a small extent of other fall crops is shown in this map.

One of the characteristics of the cropping system of the district is brought out clearly in the tabulation of the general farm crops for August. The area in hay amounts to 312.4 acres, or 28.9 per cent of the entire area. Corn, either planted alone or interplanted with cowpeas and soy beans, occupies 265 acres, or 24.4 per cent of the total. Cowpeas and millet comprise the other crops of this class.

It is the common practice in this intensively farmed region to plant as large an area as possible to the spring and early summer truck crops. As fast as these crops are harvested and the ground can be prepared, it is planted to a summer forage crop, usually corn. In order that some leguminous crop may be grown at some perod in the rotation, it is coming to be the practice to interplant either cowpeas or soy beans in the corn, or to drill or sow cowpeas broadcast upon the land. (See Pl. VI, fig. 2.) By this method a supply of forage for the work stock is produced at a period in the year when the land would not be occupied by cash crops, and many of the truckers utilize this time to grow a legume crop either for green manure or forage.

The large area in hay arises from the fact that it is almost entirely volunteer grasses, chiefly crab grass (Pl. VII, fig. 1), which spring up spontaneously upon the areas from which the spring truck crops have been harvested. This grass is allowed to come to maturity and a considerable acreage is cut for hay annually.

After these different forage crops have been harvested the land is ready for late fall or winter plowing and is used either for a winter cabbage crop or for the potato area of the next spring. This system permits the production of some forage, the growing of a green manuring crop, when desired, and the utilization of the residual effects of manures and fertilizers which have been applied to the preceding spring truck crop.

This rapid succession of crops, the interplanting of such crops as peas and beans with strawberries and cucumbers, and the year-round utilization of the land are characteristic features of the Churchland area and of the general district.

The completion of land drainage through the use of tile is probably more general in the immediate vicinity of Churchland than in other parts of the Norfolk district, but is not confined to that locality.

Another feature of the Churchland area is the common use of natural forest areas or of planted windbreaks to protect the winter and early spring crops from cold winds. The tilled areas are very commonly protected in this manner and in some cases individual fields of small area are surrounded by hedges. Such a windbreak is shown in Plate VII, figure 2.

In this area, in which the trucking industry of the district had its inception, every device for promoting the early and uninterrupted growth of crops is employed. Not only are the well-drained, somewhat sandy soils utilized as in other districts, but soils not naturally so well suited to trucking have been improved by drainage until they are available for the growing of the more important crops, such as cabbage and potatoes, and the climatic conditions above the soil have been improved by windbreaks.

The Diamond Springs Area.

During the fall of 1915 and the spring of 1916, a soil and crop map of an area of approximately 1,909 acres was made in the vicinity of Diamond Springs, Va. The territory included in this survey lies along the Cape Henry Division of the Norfolk Southern Railroad, in the northwestern part of Princess Anne County and about 7½ miles northeast of Norfolk. The southern boundary of the area is an arbitrary line, but the greater part of the eastern, northern, and northwestern boundaries is formed by the waters of Lakes Lawson and Smith and by Little Creek.

The surface of the area mapped falls into two rather distinct topographic divisions. The northern two-fifths of the area consists of a low plain whose maximum elevation of about 15 feet above tide level is attained at its southern boundary. It slopes very gently to the north, descending rather sharply to the water boundaries of the area. It consists of a series of low peninsulas, separated by narrow arms of the artificial bodies of water which surround the area on this side. The general surface is nearly level, although low ridges not more than 5 feet higher than the general surface may be detected. The surface of the plain ranges from about 8 feet to 15 feet above tide-water level. There are few stream channels within this plain except those which indent its margin.

Along the southern boundary of this plain the land rises gently to an elevation of 25 to 30 feet along the crest of a low ridge, extending in an east and west direction across the area. The surface of this ridge is somewhat uneven, being marked by slight depressions without outlets. Its crest is near its northern border whence it slopes gently toward the south and southeast. The elevations along the southern border of the area mapped range from about 15 to 20 feet above tide level.

The distribution of the soils of the area is closely related to the topographic features. The lower plain is chiefly occupied by the Norfolk loam and the Sassafras fine sandy loam. The higher portion of the ridge is occupied by the Sassafras and the Norfolk coarse sandy loam, with small isolated areas of the Norfolk loam in the depressions. The gentle southern slope of the ridge is occupied by the Sassafras loam and the Norfolk loam and gravelly loam; the lower land along the southern border of the area consists of areas of the Suffolk loam and gravelly loam. Certain of the steeper slopes around the border of the area consist of discontinuous areas of the Norfolk gravelly sandy loam.

There are few slopes within the area so steep as to interfere with cultivation. Drainage is somewhat defective in the southern part of the area, but is well established over the surface of the low ridge and fairly well established in the lower plain to the north.

Truck-crop production has been conducted within the section for a considerable period of time, and the Virginia Truck Experiment Station is situated within the limits of the area mapped. The Diamond Springs area represents the soil conditions which prevail over a considerable proportion of Princess Anne County, particularly in the northern part along Chesapeake Bay.

SOILS.

Ten different types of soil are mapped in the Diamond Springs area, exclusive of small areas of Swamp.

Sassafras coarse sandy loam.—The surface soil of the Sassafras coarse sandy loam, to an average depth of about 6 inches, is a grayish-brown medium to coarse sandy loam carrying small quantities of fine gravel. From 6 inches to 14 or 18 inches in depth the subsoil is a yellow to golden-yellow coarse sandy loam. This is underlain to a depth of about 36 inches by a crumbly but decidedly coherent sandy loam, containing a large proportion of coarse sand mixed with silt and clay. In many places the material changes below 36 inches to a coarse loamy sand of an orange color. Fine gravel is found at all depths.

This type occupies the highest elevations within the area. It is naturally well drained and somewhat porous. The more coherent deep subsoil, however, prevents extreme droughtiness.

A large part of the Sassafras coarse sandy loam has been cleared, and is used for the production of both spring and winter truck crops.

Sassafras fine sandy loam.—The surface soil of the Sassafras fine sandy loam consists of 5 to 8 inches of brown fine sandy loam. The upper subsoil, to a depth of about 16 inches, is a reddish-yellow to orange fine sandy loam. Below 16 inches the subsoil is a rather heavy reddish-brown fine sandy loam or light loam. In some cases a bed of orange sand and fine gravel is encountered at 34 to 36 inches below the surface.

The Sassafras fine sandy loam occupies the higher elevations on the low ridges or swells occurring in the lower plain. It is also found along the margins of the deeper drainage ways. In all positions its natural drainage is good.

The type differs slightly from the occurrences in the Churchland area. Both soil and subsoil contain rather more medium and coarse sand and less fine sand, while there is also a larger amount of silt in the deeper subsoil. The type is possibly slightly more retentive of moisture in the Diamond Springs area than in the Churchland area. It is used for the growing of both forage and truck crops in the Diamond Springs area.

Sassafras loam.—The surface soil of the Sassafras loam is a brown, friable loam, 6 inches or more deep, containing in many places some fine gravel and coarse sand. From 6 to 36 inches or more the subsoil is a reddish-brown loam, distinctly compact and heavy.

The Sassafras loam is found on nearly level upland areas adjacent to the deeper-cut drainage ways. Drainage is excellent and the type is cleared and occupied by truck crops nearly to the limit of its extent.

Norfolk coarse sandy loam.—The surface soil of the Norfolk coarse sandy loam, to a depth of 5 inches, is a yellowish-brown coarse sandy loam. A varying amount of fine gravel is found throughout the surface soil. From 5 to 16 or 18 inches in depth the subsoil is a yellow coarse sandy loam. This is underlain to a depth of 36 inches or more by a rather heavy, yellow sandy loam.

The Norfolk coarse sandy loam occurs along the crest of the low ridge extending through the center of the area, in close association with the Sassafras coarse sandy loam. The surface is only gently sloping. Drainage is good to rather excessive. The greater part of the type is cleared and under cultivation.

Norfolk loam.—The surface soil of the Norfolk loam, to a depth of 4 or 5 inches, is a grayish-brown loam, containing enough very fine sand to render it soft and friable. The subsoil, to a depth of 32 inches or more, is a yellow loam sufficiently high in silt and clay to

make it compact and stiff. In some cases compaction amounts almost to a "hardpan" condition. The deeper subsoil in places is a pale yellow coarse sandy loam.

The larger areas of the Norfolk loam lie in the lower plain where the surface is nearly level. In such locations drainage is not completely established and the deeper subsoil is frequently found to be saturated. The areas of greatest extent at the higher levels are fairly well drained under natural conditions, but can be improved by the installation of tile. Some small areas, not typical, occur in the slight depressions of the higher plain. These possess no natural outlet for drainage and the deep subsoil is inclined to be wet.

A part of this type has been cleared and used for the production of both forage and truck crops. By far the larger part, including large areas in the lower plain, are uncleared or partly overgrown with second-growth (see Pl. IV, fig. 2) oak and pine. The type is not highly esteemed for truck-crop production, but may be so used if underdrainage is installed, as has been shown upon the grounds of the Virginia Truck Experiment Station.

Norfolk silt loam.—The surface soil of the Norfolk silt loam consists of 10 or 12 inches of yellowish-brown silt loam. The subsoil, to 36 inches or more in depth, is a stiff, compact, pale-yellow silt loam. The type is developed only in one small, depressed area upon the Experiment Station Farm and probably represents an accumulation of fine material washed in from the surrounding area of Norfolk loam. So far as is known this soil does not occur extensively within the general region.

Norfolk gravelly loam.—To a depth of 5 or 6 inches the surface soil of the Norfolk gravelly loam is a gray to yellowish-brown, gravelly sandy loam. The fine gravel and coarse sand are decidedly apparent, but there is enough fine-grained material present to cause the surface to clod and bake after rains. The subsoil, from 5 to 16 inches in depth, is a coarse-grained gravelly sandy loam. From 16 to 36 inches or more the deep subsoil is a sticky, yellow gravelly loam. This deep subsoil is frequently compacted and mortarlike.

The surface of the type is nearly level to slightly sloping. The natural drainage conditions are only fair or, over some areas, decidedly defective. A considerable part of this soil remains in forest and the remainder is farmed with a variety of truck and market garden crops. The settlement of colored farmers near Burton is partly located on this soil.

Norfolk gravelly sandy loam.—The surface soil of the Norfolk gravelly sandy loam is a gray to yellow coarse sandy loam, 6 or 8 inches deep. A large amount of fine gravel is usually present. The subsoil is a coarse, loamy yellow sand. It is usually underlain by a heavier yellow sandy loam.

This soil occurs chiefly on the steeper slopes from the upland to water level and around the stream heads. It consists largely of coarse sandy wash from upland types. Drainage is excessive and the material is subject to additions and removals of soil material due to erosion. It is chiefly forested, although small areas extend into tilled fields.

Suffolk gravelly loam.—The surface soil of the Suffolk gravelly loam is a grayish-brown gravelly loam, with a depth of 8 inches. This is underlain by a pale-gray gravelly loam to 36 inches or more. The deeper subsoil is usually saturated.

The type occurs in level or depressed areas where natural drainage is poor. A large part is in forest and the remainder is farmed to various crops, chiefly by colored farmers.

Suffolk loam.—The Suffolk loam consists of 4 or 5 inches of dark gray loam, underlain by a subsoil of gray silty loam, which extends to a depth of 36 inches. A small amount of fine gravel is found in the soil and subsoil. The deeper subsoil is usually saturated. The type occupies depressed areas and is poorly drained. It is chiefly in forest.

Swamp.—A few small areas of Swamp occur around the margin of the Diamond Springs area. These lie at water level and are not easily drained.

It is apparent that a considerable diversity of soil texture and of natural conditions of drainage exists within the Diamond Springs area. The three soils of the Sassafras series and the Norfolk coarse sandy loam are well drained. The Norfolk silt loam, loam, and gravelly loam are but moderately drained. The Suffolk loam and gravelly loam are poorly drained. These facts become evident in the crop uses of the different soil types.

USES OF SOILS.

The completed soil and crop maps for November, 1915, and for June, 1916, were measured in order to show the relative and absolute uses of each soil for the production of the different crops and groups of crops. The areas given for November represent the fall and winter conditions; those for June represent the spring and early summer crop areas. Some areas of crops which had been marketed in the early spring are not shown.

Tables IV and V give the statistics in detail, the former showing conditions in June and the latter in November.

TABLE IV.—*Proportion of total area and of the area of each soil type occupied by various crops and groups of crops, Diamond Springs area, June, 1916.*

Crop and group of crops.	All soils.		Sassafras coarse sandy loam.		Sassafras fine sandy loam.		Sassafras loam.		Norfolk coarse sandy loam.		Norfolk loam.	
	Acres.	Per cent.	Acres.	Per cent.	Acres.	Per cent.	Acres.	Per cent.	Acres.	Per cent.	Acres.	Per cent.
General farm crops	240.4	12.6	29.1	10.5	41.8	27.1	2.5	2.4	13.5	4.6	57.4	11.6
Hay and pasture	14.8	.8	2.7	1.0	2.2	1.4	.....	.....	2.6	.9	4.0	.8
Corn	193.2	10.1	26.4	9.5	30.3	19.7	.....	.....	10.9	3.7	44.0	8.9
Wheat	15.1	.8	.....	.....	9.3	6.0	.....	.....	.....	.....	5.8	1.2
Oats	9.3	.5	.....	.....	.....	.....	.....	.....	.....	.....	3.6	.7
Cowpeas	8.0	.4	.....	.....	.....	.....	2.5	2.4	.....	.....	.....	.....
Truck crops	674.7	35.5	152.6	54.8	23.5	15.2	69.3	67.3	198.8	68.3	67.2	13.6
Strawberries	248.3		83.7		.2		20.2		70.2		40.4	
Strawberries and potatoes	21.1	15.1	16.4	36.1	.....	.1	.....	23.7	.5	27.6	.7	8.3
Strawberries and beans	16.8		.2		.....		4.2		9.3		.....	
Cabbage	118.1	6.2	16.9	6.0	.2	.1	22.7	22.0	50.6	17.4	14.0	2.8
Potatoes	111.1	5.8	12.7	4.5	6.0	3.9	4.8	4.7	63.2	21.7	6.0	1.2
Beans	71.7	3.8	10.0	3.6	10.2	6.6	3.6	3.5	1.5	.5	1.7	.4
Sweet potatoes	28.8	1.5	8.0	2.9	.....	.....	5.5	5.3	1.8	.6	1.5	.3
Cucumbers	18.4	1.0	.....	.....	6.9	4.5	.5	.5	.4	.1	.4	.1
Tomatoes	10.2	.5	.....	.....	.....	.....	.2	.2	.....	.....	.....	.....
Cantaloupe	9.1	.5	.....	.....	.....	.....	7.6	7.4	.....	.....	.....	.....
Radish	8.0	.4	4.7	1.7	.....	.....	.....	.....	1.3	.4	1.5	.3
Pumpkin and squash	7.7	.4	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Miscellaneous truck crop	5.4	.3	.....	.....	.....	.....	.....	.....	.....	.....	1.0	.2
No annual crop	985.7	51.9	96.5	34.7	88.7	57.6	31.1	30.2	78.8	27.1	370.8	74.9
Forest	573.4	30.2	58.2	21.0	44.0	28.6	11.8	11.5	56.4	19.4	200.3	40.4
No crops	329.4	17.3	21.8	7.8	36.7	23.8	16.7	16.2	10.2	3.5	165.6	33.5
Garden and grounds	55.3	2.9	12.7	4.6	7.3	4.7	2.6	2.5	6.5	2.2	3.1	.6
Orchard and vineyard	27.6	1.5	3.8	1.3	.7	.5	.....	.....	5.7	2.0	1.8	.4
Grand total	1,900.8	100.0	278.2	100.0	154.0	99.9	102.9	99.9	291.1	100.0	495.4	100.1

Crop and group of crops.	Norfolk gravelly loam.		Suffolk gravelly loam.		Suffolk loam.		Norfolk gravelly sandy loam.		Norfolk silt loam.		Swamp.	
	Acres.	Per cent.	Acres.	Per cent.	Acres.	Per cent.	Acres.	Per cent.	Acres.	Per cent.	Acres.	Per cent.
General farm crops	38.7	14.6	12.8	17.6	43.2	22.1	1.4	4.1	.....	.....	.....	.....
Hay and pasture	.....	.....	.4	.5	1.5	.8	1.4	4.1	.....	.....	.....	.....
Corn	32.8	12.4	9.1	12.6	39.7	20.3	.....	.....	.....	.....	.....	.....
Wheat	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Oats	2.6	1.0	2.9	4.0	.2	.1	.....	.....	.....	.....	.....	.....
Cowpeas	3.3	1.2	.4	.5	1.8	.9	.....	.....	.....	.....	.....	.....
Truck crops	95.2	36.1	30.1	41.7	34.1	17.4	3.9	11.2	.....	.....	.....	.....
Strawberries	15.7		4.4		13.5							
Strawberries and potatoes	.....	6.8	.....	6.1	.....	7.3	3.5	10.0	.....	.....	.....	.....
Strawberries and beans	2.4		.....		.7							
Cabbage	6.6	2.5	3.1	4.3	3.8	2.0	.2	.6	.....	.....	.....	.....
Potatoes	14.2	5.4	3.1	4.3	.9	.4	.2	.6	.....	.....	.....	.....
Beans	25.1	9.5	8.7	12.0	10.9	5.6	.....	.....	.....	.....	.....	.....
Sweet potatoes	6.9	2.6	3.5	4.8	1.6	.8	.....	.....	.....	.....	.....	.....
Cucumbers	5.1	1.9	4.4	6.1	.7	.3	.....	.....	.....	.....	.....	.....
Tomatoes	9.3	3.5	.7	1.0	.....	.....	.....	.....	.....	.....	.....	.....
Cantaloupe	1.5	.6	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Radish	.5	.2	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Pumpkin and squash	5.5	2.1	1.5	2.1	.7	.3	.....	.....	.....	.....	.....	.....
Miscellaneous truck	2.4	.9	.7	1.0	1.3	.7	.....	.....	.....	.....	.....	.....
No annual crop	130.1	49.3	29.3	40.7	117.6	60.3	29.3	84.7	9.0	100.0	4.5	100.0
Forest	65.1	24.7	14.2	19.7	97.9	50.2	25.5	73.7	.....	.....	.....	.....
No crops	41.9	15.9	8.0	11.1	13.2	6.8	1.8	5.2	9.0	100.0	4.5	100.0
Garden and grounds	13.8	5.2	3.1	4.3	5.8	3.0	.4	1.1	.....	.....	.....	.....
Orchard and vineyard	9.3	3.5	4.0	5.6	.7	.3	1.6	4.7	.....	.....	.....	.....
Grand total	264.0	100.0	72.2	100.0	194.9	99.8	34.6	100.0	9.0	100.0	4.5	100.0

TABLE V.—*Proportion of total area and of the area of each soil type occupied by various crops and groups of crops, Diamond Springs area, November, 1915.*

Crop and group of crops.	All soils.		Sassafras coarse sandy loam.		Sassafras fine sandy loam.		Sassafras loam.		Norfolk coarse sandy loam.		Norfolk loam.	
	Acres.	Per cent.	Acres.	Per cent.	Acres.	Per cent.	Acres.	Per cent.	Acres.	Per cent.	Acres.	Per cent.
General farm crops	289.0	15.1	35.0	12.6	16.9	10.9	2.5	2.4	38.5	13.1	87.1	17.5
Hay and pasture	23.3	1.2	2.2	.8	2.7	1.7	.....	.....	2.2	.7	4.3	.9
Corn	188.5	9.9	9.4	3.4	14.2	9.2	.9	.9	29.9	10.2	60.3	12.1
Corn and cowpeas	36.7	1.9	15.5	5.6	.....	.....	.....	.....	2.3	.8	9.2	1.8
Soy beans	19.6	1.0	7.9	2.8	.....	.....	1.6	1.5	4.1	1.4	6.0	1.2
Oats	8.4	.4	.....	.....	.....	.....	.....	.....	.....	.....	.5	.1
Sorghum	6.8	.4	.....	.....	.....	.....	.....	.....	.....	.....	6.8	1.4
Cowpeas	5.7	.3	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Truck crops	632.9	33.2	155.4	55.7	49.5	32.0	67.5	66.1	165.8	56.6	61.7	12.3
Spinach	257.5	13.5	65.7	23.5	40.5	26.2	54.7	53.5	48.8	16.6	27.9	5.6
Strawberries	132.1		41.2		.....	.....	9.2		34.2		12.8	
Strawberries and beans	74.5	11.0	34.0	27.5	.....	.....	1.6	10.6	25.2	21.2	11.0	4.8
Strawberries and peas	4.3		1.4		.....	.....	.....		2.7		.2	
Cabbage	36.9	2.0	.7	.3	.....	.....	1.3	1.3	19.2	6.6	2.2	.4
Kale	31.2	1.6	4.0	1.4	4.0	2.6	.....	.....	14.4	4.9	3.6	.7
Potatoes	28.5	1.5	.....	.....	5.0	3.2	.7	.7	19.2	6.6	.9	.2
Beans	25.1	1.3	4.0	1.4	.....	.....	.....	.....	1.4	.5	2.2	.4
Turnips	20.7	1.1	.4	.1	.....	.....	.....	.....	.....	.....	.....	.....
Sweet potatoes	10.0	.5	2.7	1.0	.....	.....	.....	.....	.....	.....	.4	.1
Tomatoes	5.0	.3	.....	.....	.....	.....	.....	.....	.7	.2	.5	.1
Misc. truck crops	7.1	.4	1.3	.5	.....	.....	.....	.....	.....	.....	.....	.....
No annual crop	981.5	51.6	88.5	31.7	88.2	57.0	32.2	31.5	88.7	30.3	348.2	70.0
Forest	601.7	31.6	64.3	23.0	44.0	28.5	12.9	12.6	68.8	23.5	205.6	41.3
No crop	322.0	16.9	14.8	5.3	36.2	23.4	18.7	18.3	11.7	4.0	137.9	27.7
Garden and grounds	35.9	2.0	5.8	2.1	7.3	4.7	.6	.6	2.4	.8	2.9	.6
Orchard and vineyard	20.9	1.1	3.6	1.3	.7	.4	.....	.....	5.8	2.0	1.8	.4
Grand total	1,903.4	99.9	278.9	100.0	154.6	99.9	102.2	100.0	293.0	100.0	497.0	99.8

Crop and group of crops.	Norfolk gravelly loam.		Suffolk gravelly loam.		Suffolk loam.		Norfolk gravelly sandy loam.		Norfolk silt loam.		Swamp.	
	Acres.	Per cent.	Acres.	Per cent.	Acres.	Per cent.	Acres.	Per cent.	Acres.	Per cent.	Acres.	Per cent.
General farm crops	54.8	20.7	23.0	32.2	27.6	14.3	3.6	10.4	.....	.....	.....	.....
Hay and pasture	1.4	.5	.....	.....	7.4	3.8	3.1	9.0	.....	.....	.....	.....
Corn	38.7	14.6	15.3	21.4	19.3	10.0	.5	1.4	.....	.....	.....	.....
Corn and cowpeas	6.8	2.6	2.9	4.1	.....	.....	.....	.....	.....	.....	.....	.....
Soy beans	4.7	1.8	3.2	4.5	.....	.....	.....	.....	.....	.....	.....	.....
Sorghum	3.2	1.2	1.6	2.2	.9	.5	.....	.....	.....	.....	.....	.....
Truck crops	73.5	27.7	17.2	23.9	39.6	20.4	2.7	7.8	.....	.....	.....	.....
Spinach	13.0	5.0	2.0	2.8	2.2	1.1	2.7	7.8	.....	.....	.....	.....
Strawberries	16.2		4.1		14.4		.....	.....	.....	.....	.....	.....
Strawberries and beans	.....	6.1	.....	5.7	2.7	8.8	.....	.....	.....	.....	.....	.....
Strawberries and peas	.....		.....		.....		.....	.....	.....	.....	.....	.....
Cabbage	6.1	2.3	1.6	2.2	5.8	3.0	.....	.....	.....	.....	.....	.....
Kale	4.0	1.5	.7	1.0	.5	.3	.....	.....	.....	.....	.....	.....
Potatoes	1.8	.7	.....	.....	.9	.5	.....	.....	.....	.....	.....	.....
Beans	12.1	4.5	1.8	2.5	3.6	1.8	.....	.....	.....	.....	.....	.....
Turnips	9.4	3.5	4.1	5.7	6.8	3.5	.....	.....	.....	.....	.....	.....
Sweet potatoes	3.8	1.5	1.3	1.8	1.8	.9	.....	.....	.....	.....	.....	.....
Tomatoes	2.2	.8	1.1	1.5	.5	.3	.....	.....	.....	.....	.....	.....
Misc. truck crops	4.9	1.8	.5	.7	.4	.2	.....	.....	.....	.....	.....	.....
No annual crop	136.4	51.5	31.3	43.8	126.2	65.3	28.3	81.8	9.0	100.0	4.5	100.0
Forest	67.5	25.5	14.2	19.7	97.9	50.7	26.5	76.6	.....	.....	.....	.....
No crop	57.1	21.6	10.3	14.4	21.8	11.3	.....	.....	9.0	100.0	4.5	100.0
Garden and grounds	8.6	3.2	3.1	4.5	5.8	3.0	.4	1.2	.....	.....	.....	.....
Orchard and vineyard	3.2	1.2	3.7	5.2	.7	.3	1.4	4.0	.....	.....	.....	.....
Grand total	264.7	99.9	71.5	99.9	193.4	100.0	34.6	100.0	9.0	100.0	4.5	100.0

SOIL AND CROP ACREAGES FOR JUNE.

The measurements for June show that 674.7 acres of land, or 35.5 per cent of the total area, are occupied by truck crops. The general farm crops occupy 240.4 acres, or 12.6 per cent of the area. No annual

crops are grown upon 985.7 acres, or 51.9 per cent of the area mapped. Forest occupies 573.4 acres, or 30.2 per cent of all the land area, and an additional area of 329.4 acres of land is not in commercial crops.

The figures given for "All soils" establish a standard of crop occupations for the area and it is possible to make comparison of the relative areas of the different crops and groups of crops for each soil type with this standard.

The Norfolk coarse sandy loam, Sassafras coarse sandy loam, and Sassafras loam all carry a high percentage of truck crops.

The Sassafras fine sandy loam, the Norfolk gravelly loam, and the Suffolk loam and gravelly loam all carry a percentage of the general farm crops above the average.

The Norfolk loam, Suffolk loam, and Norfolk gravelly sandy loam carry a high percentage of forested area.

Strawberries, either grown alone or interplanted with potatoes or beans, occupy 286.2 acres. This is a larger area than in any other spring truck crop and amounts to 15 per cent of the total area mapped. (See Pl. VIII, figs. 1 and 2.)

Cabbage ranks second among truck crops, covering 118.1 acres or 6.2 per cent of the area.

Irish Cobbler potatoes cover 111.1 acres and are interplanted with strawberries to an additional extent of 21.1 acres.

Snap and lima beans occupy 71.7 acres, to which should be added an area of 16.8 acres, interplanted with strawberries. (See Pl. IX, figs. 1 and 2.)

The remaining truck crops occupy subordinate acreages, with sweet potatoes, cucumbers, tomatoes, and cantaloupes as the leading crops.

Among the general farm crops corn is by far the most important, occupying 192.3 acres, or 10.1 per cent of the total area mapped.

The large area not occupied by any crop is caused by the fact that a considerable part of the Norfolk loam and a part of the Sassafras fine sandy loam, both occurring in the lower plain, are included in a tract not regularly farmed. The crop areas of the Virginia Truck Experiment Station farm [2] are not measured and included in

[2] The following table gives the area of the several soils in this tract:

Soils of the Virginia Truck Experiment Station farm.

Soil type.	In forest.	Experimental plots and station grounds.	Total area.
	Acres.	*Acres.*	*Acres.*
Sassafras coarse sandy loam	0.7	6.7	7.4
Sassafras loam	.....	3.8	3.8
Norfolk coarse sandy loam	4.7	3.4	8.1
Norfolk gravelly sandy loam	.....	1.4	1.4
Norfolk gravelly loam	.....	10.3	10.3
Norfolk silt loam	.....	9.0	9.0
Norfolk loam	3.6	20.3	23.9
	9.0	54.9	63.9

the crop tabulation since they are handled chiefly for experimental purposes. At the time of the survey potatoes occupied the greater part of this acreage, while cabbage, strawberries, and cucumbers with some forage crops and orchard occupied the remainder.

The distribution of the various spring crops upon the different soil types shows a selection of the Sassafras coarse sandy loam and the Norfolk coarse sandy loam for the growing of strawberries. These well-drained soils are capable of maturing an early crop, which is desired in order to obtain the higher prices. The Sassafras loam also is extensively planted to strawberries.

The same group of soils leads in cabbage area. The largest number of acres is found on the Norfolk coarse sandy loam, while the highest percentage of total acreage in cabbage is found on the Sassafras loam. Approximately one-half of the total area of Irish potatoes is found on the Norfolk coarse sandy loam, and this type appears to be distinctly preferred for the crop, 21.7 per cent of its area being thus occupied.

Of the beans, snap beans appear chiefly upon the Sassafras coarse sandy loam and fine sandy loam and pole lima beans upon the Norfolk gravelly loam and the Suffolk loam and gravelly loam. The latter crop is very extensively grown by the colored farmers in the vicinity of Burton, which accounts largely for the use of these soils for bean growing.

The distribution of the other truck crops is not especially significant.

SOIL AND CROP ACREAGES FOR NOVEMBER.

The November, 1915, crop map shows about the same proportionate distribution of area between general farm crops and truck crops as is shown by the map for June, 1916. The forage crops occupy 289 acres, or 15.1 per cent of the entire area. The truck crops cover 632.9 acres, or almost exactly one-third of the total area mapped.

Among the general farm crops, corn leads in acreage. It covers 188.5 acres, planted alone, and an additional area of 36.7 acres in combination with cowpeas. It thus occupies 11.8 per cent of the whole area.

Hay and pasture, soy beans, and subordinate forage crops occupy 63.8 acres, or 3.3 per cent of the area.

Spinach is the winter truck crop most extensively grown in this locality, occupying 275.5 acres, or 13.5 per cent of the total area. (See Pl. X, fig. 1.)

Strawberries, either planted alone or with a fall crop of peas or snap beans, occupy 210.9 acres, or 11 per cent of the area.

Beans, interplanted with strawberries, occupy 74.5 acres, while beans planted alone, chiefly pole limas, occupy an additional area of 25.1 acres.

Cabbage, covering 36.9 acres, kale to the extent of 31.2 acres, and fall potatoes, covering 28.5 acres, are the other important fall and winter truck crops.

The area in forest is higher than on the June map, as some forested land was cleared and placed under cultivation in the winter of 1915–16. The area of cleared land not cropped is high from the fact that a considerable tract was not being farmed.

The restrictions of winter truck crops to certain soil types is rather marked. The Sassafras and Norfolk coarse sandy loams occupy only 30 per cent of the total area mapped, but they carry more than 50 per cent of the total acreage of truck crops. The Sassafras fine sandy loam and loam are also important truck crop soils. The Norfolk loam, Norfolk gravelly loam, the Suffolk gravelly loam, and Suffolk loam cover nearly 51 per cent of the area but support only 30.3 per cent of the truck crop acreage.

It is evident that only the best drained soils of the locality are utilized for growing the crops which occupy the land during the winter or throughout the year.

With reference to individual truck crops, it appears that spinach is grown chiefly on the Sassafras loam, which carries 54.7 acres, or 53.5 per cent of its area, in the crop; on the Sassafras fine sandy loam, bearing 40.5 acres, or 26.2 per cent of its area in spinach; and on the Sassafras coarse sandy loam, which carries 65.7 acres, or 23.5 per cent of its area in that crop. As the Norfolk coarse sandy loam bears 48.8 acres of spinach, or 16.6 per cent of its area, nearly 80 per cent of the entire acreage of spinach is found on these 4 types of soil.

Nearly two-thirds of the acreage in strawberries occurs on the Sassafras and Norfolk coarse sandy loams. This is fairly comparable with the spring conditions, since the crop continues on the ground throughout the year.

The largest acreage in cabbage is on the Norfolk coarse sandy loam, 19.2 acres, or 6.6 per cent of the area of the type. This is a little more than one-half of the total fall planting of cabbage. The greater part of the remaining acreage in cabbage occurs on the Norfolk gravelly loam and the Suffolk loam.

The Norfolk coarse sandy loam carries nearly one-half of the total area of kale.

More than two-thirds of the fall potato crop is planted on the Norfolk coarse sandy loam.

The fall crop of snap beans is chiefly interplanted with strawberries on the Sassafras and Norfolk coarse sandy loams, while a large part of the pole lima bean crop is grown on the Norfolk gravelly loam.

Several characteristic features of the cropping system followed in the section around Diamond Springs are shown by the two maps.

Approximately one-half of the total area mapped is used for the growing of general farm crops and truck crops; the remainder is in forest, gardens and grounds, orchards, and the experimental plots, or else is unoccupied for farming purposes.

The truck crops occupy about one-third of the total area, both in fall and in spring. Among these crops, strawberries cover the largest acreage, except during the winter months, when the acreage in spinach is slightly larger.

The considerable acreage given to cabbage growing is notable.

The subordinate position of potatoes in both spring and fall and of kale among the fall crops is marked.

The growing of snap beans, interplanted with strawberries, is a feature of the cropping on the coarse sandy loam soils.

The relatively large area given to forage and grain crops in the spring is in somewhat marked contrast with the conditions shown by the June crop map of the Churchland area. The larger area of heavy soils in the Diamond Springs area accounts for this, in part. The fact that corn frequently succeeds spinach, cabbage, and such strawberry beds as are plowed out after finishing their bearing period also influences the acreage of corn.

Comparison of the Churchland and Diamond Springs Areas.

Although the Churchland and Diamond Springs areas lie within a few miles of each other, under closely similar climatic conditions and with almost equal accessibility to shipping points, the two areas show some notable contrasts in the character of cultivation, especially with respect to the growing of truck crops.

The Churchland area is dominated by fine sandy loam soils which occupy over 95 per cent of its total area. The Diamond Springs area is marked by a considerable diversity of soil types. The loam soils cover 42 per cent of the total area; gravelly loams occupy 18 per cent; coarse sandy loams cover 30 per cent, and one fine sandy loam soil comprises but 8 per cent of the total area mapped. Thus, nearly 60 per cent of the total area consists of rather heavy soils.

In the Churchland area two-thirds of the upland area consists of naturally well-drained soils, while the other types have been decidedly modified with regard to drainage by the tile underdrainage. The soils of the Diamond Springs area may be grouped into three classes with respect to their natural drainage. The Sassafras loam, fine sandy loam, and coarse sandy loam and the Norfolk coarse sandy loam are naturally well drained. These four types occupy 43 per cent of the total area. The Norfolk loam and gravelly loam are only moderately well drained in their natural condition, and little artificial drainage has been installed. They cover 40 per cent of the total area. The Suffolk loam and gravelly loam are dis-

tinctly poorly drained. They cover approximately 14 per cent of the area.

These conditions of soil texture and of drainage are reflected strongly in the cropping of the two areas.

The Churchland area is one of very complete agricultural occupation. About 88 per cent of the upland is occupied by some crop. The area in forest is relatively small, amounting to about 4 per cent of the total. The greater part of this occurs in one tract upon the Suffolk fine sandy loam, to which artificial drainage has not yet been extended. In the Diamond Springs area cultivation occupies but 48 per cent of the total area, 30 per cent is in forest, and 17 per cent of the cleared area is occupied for experimental purposes or is not tilled. The occurrence of large tracts of forest on the Norfolk loam and gravelly loam and upon the Suffolk loam is notable. These types need additional drainage facilities to become available for the growing of any truck crops.

A comparison of the spring cropping conditions shows that 87 per cent of the Churchland area is occupied by truck crops, while 35 per cent of the Diamond Springs area is so cropped. Potatoes are by far the most extensively planted crop in the Churchland area, covering nearly 57 per cent of the ground. Strawberries are as emphatically the leading crop in the Diamond Springs area, occupying 15 per cent of the area. In both areas cabbage occupies second place. Snap beans, cucumbers, strawberries, and garden peas are the other important spring crops in the Churchland area. Potatoes and snap and pole lima beans are of importance in the Diamond Springs area.

In both areas the spring truck crops occupy a large proportion of the area available for farming.

The fall crop conditions in the two areas are not quite so directly comparable, since the surveys were made in two different years and not precisely at the same cropping period. Yet it is rather significant that kale leads among the fall truck crops in the Churchland area (Pl. X, fig. 2), while spinach leads in the Diamond Springs area. Strawberries, which occupy the land during the year, show a large fall acreage in the Diamond Springs area. In the Churchland area spinach and a fall crop of potatoes are almost equally important. In the Diamond Springs area the winter planting of cabbage for spring harvest is second to spinach in area, and the fall crop of potatoes is of rather small extent.

In the Churchland area only a moderate proportion of the available area is given to fall and winter crops, whereas in the Diamond Springs area the fall and winter cropping is almost equal to the spring area.

In the Churchland area the fall crops are somewhat concentrated on the Sassafras and Norfolk fine sandy loams. Kale and spinach are especially segregated on these types, while the fall potato crop occurs on the Norfolk and Keyport fine sandy loams.

In the Diamond Springs area nearly 70 per cent of the total acreage of fall and winter truck crops is found on the four best-drained soils, 51 per cent occurring on the two coarse sandy loams.

It thus appears that the growing of truck crops upon the different soils of the Norfolk trucking district is most strongly affected by drainage conditions resulting (1) from the texture of the soil types and (2) from the physical position of the soils with regard to natural or artificial outlets for drainage waters.

This results in the utilization of the coarser-grained and better drained types for the growing of winter crops or those which occupy the ground throughout the year; in the use of soils of intermediate texture, like the fine sandy loams for the growing of large areas of spring truck crops; and in the use of the loam soils and others of less perfect drainage for the growing of forage crops or in their remaining out of cultivation. The notable exception to this general condition is found in the case of the Sassafras loam. This type is naturally well drained and has been utilized extensively for truck crop production, although its texture is somewhat fine grained for such use.

Tables VI and VII show in detail the more important uses of each extensive soil type for the production of each important truck crop in spring and fall, respectively.

TABLE VI.—*Areas of important spring truck crops on the more important soils of the Diamond Springs areas.*

Soil type and crop.	Acres.	Per cent of type.
Sassafras coarse sandy loam:		
Strawberries	100.3	36.1
Cabbage	16.9	6.0
Potatoes	12.7	4.5
Norfolk coarse sandy loam:		
Strawberries	80.0	27.5
Potatoes	63.2	21.7
Cabbage	50.6	17.4
Sassafras fine sandy loam:		
Potatoes	97.1	28.2
Cucumbers	27.7	8.0
Cabbage	18.9	5.5
Norfolk fine sandy loam:		
Potatoes	299.0	61.2
Cabbage	48.8	10.0
Beans[1]	34.4	7.0
Keyport fine sandy loam:		
Potatoes	123.4	58.6
Cabbage	48.3	23.0
Cucumbers	15.3	7.3
Suffolk fine sandy loam:		
Potatoes	71.8	49.2
Cabbage	20.6	14.1
Beans[1]	6.2	4.3
Sassafras loam:		
Strawberries	24.4	23.7
Cabbage	22.7	22.0
Norfolk loam:		
Strawberries	41.1	8.3
Cabbage	14.0	2.8
Suffolk loam:		
Strawberries	14.2	7.3
Beans[2]	10.9	5.6
Norfolk gravelly loam:		
Beans[2]	25.1	9.5
Strawberries	18.1	6.8
Potatoes	14.2	5.4
Suffolk gravelly loam:		
Beans[2]	8.7	12.0
Strawberries	4.4	6.1

[1] Snap beans.

[2] Pole lima beans, chiefly.

TABLE VII.—*Areas of important fall truck crops on the more important soils of the Diamond Springs areas.*

Soil type and crop.	Acres.	Per cent of type.	Soil type and crop.	Acres.	Per cent of type.
Sassafras coarse sandy loam:			Keyport fine sandy loam:		
Strawberries [1]	76.6	27.5	Kale	27.9	13.3
Spinach	65.7	23.5	Potatoes	17.3	8.3
Norfolk coarse sandy loam:			Sassafras loam:		
Strawberries [1]	62.1	21.2	Spinach	54.7	53.5
Spinach	48.8	16.6	Strawberries [1]	10.8	10.6
Sassafras fine sandy loam:			Suffolk fine sandy loam, kale	8.4	5.7
Spinach	76.6	22.2	Norfolk loam:		
Kale	36.7	10.6	Spinach	27.9	5.6
Norfolk fine sandy loam:			Strawberries [1]	24.0	4.6
Kale	84.1	17.1	Norfolk gravelly loam:		
Potatoes	36.5	7.4	Strawberries [1]	16.2	6.1
Spinach	26.0	5.3	Spinach	13.0	5.0
Strawberries [1]	22.9	4.7	Suffolk gravelly loam:		
			Strawberries [1]	4.1	5.4
			Turnips	4.1	5.4

[1] Occupy the ground throughout the year.

SOIDS PREFERRED FOR DIFFERENT TRUCK CROPS.

The soil and crop surveys of the Churchland and the Diamond Springs areas indicate a preference of certain soil types in the growing of certain crops. Such preference is brought out in the following recapitulation:

Potatoes.—Potatoes are the most important spring truck crop in the Norfolk district. The maps show a total of 746.7 acres in this crop. The four fine sandy loam types carry 591.3 acres, or 79.1 per cent of the total. The types constitute a little less than 35 per cent of the total area mapped. The fall crop of potatoes covers 88.8 acres, and of this total 53.8 acres consist of the Norfolk and Keyport fine sandy loams. This constitutes over 60 per cent of the area of the fall-grown crop. The preference for the fine sandy loam soils for potato growing is thus marked.

Strawberries.—The spring crop maps show a total area of 336.3 acres in strawberries. The Sassafras and Norfolk coarse sandy loams carry 180.3 acres of strawberries, or nearly 54 per cent of the total acreage, although they cover less than 20 per cent of the total area mapped. The Sassafras loam is the only other important type used for strawberry growing within the sections mapped.

Cabbage.—The cabbage crop occupies 260.8 acres, rather evenly distributed on the Keyport fine sandy loam, the Norfolk coarse sandy loam, and the Norfolk fine sandy loam. Over 56 per cent of the crop is found on these three types.

Beans.—The spring crop of snap beans occurs largely on the Norfolk fine sandy loam, while the pole lima bean crop is chiefly on the Norfolk gravelly loam. The latter crop is exceptional in the Norfolk district.

Cucumbers.—Out of a total acreage of 70.2 acres of cucumbers, 43 acres, or 61.2 per cent, consist of the Sassafras and Keyport fine sandy loams.

Spinach.—Spinach is the most extensively grown winter truck crop in the Norfolk district. The total area in the two areas mapped is 328.3 acres. The Sassafras loam carries 54.7 acres, or 52.1 per cent of its total area, in spinach; the Sassafras coarse sandy loam 65.7 acres, or 23.5 per cent of its area; the Sassafras fine sandy loam bears 76.6 acres, or 22.2 per cent of its total extent; and the Norfolk coarse sandy loam carries 48.8 acres, or 16.6 per cent of its total area. From this it follows that the best-drained soils of the Norfolk district include nearly 75 per cent of the spinach area mapped in the two surveys.

Kale.—Kale is the other winter crop of importance in the Norfolk district. A total area of 188.2 acres is accredited to this crop, chiefly in the Churchland area. The Norfolk, Sassafras, and Keyport fine sandy loams carry a total of 148.7 acres, or 79 per cent of all of the kale mapped. They cover about 42 per cent of the area surveyed.

Only the more sandy soils are desired for the growing of watermelons and cantaloupes.

Sweet potatoes, cucumbers, and peas show quite a range of desirable soil conditions, with a rather marked preference for sandy loams and even for sands.

The preferred soils for potatoes and beans are very decidedly the sandy loam types. The production of the latter crop on loams is also indicated.

The preferences of soils for strawberries range toward the sandy loam and the loam soils, although heavier soils may be used.

Spinach and kale are preferably grown upon the heavier and more loamy soils.

SOIL PREFERENCES EXPRESSED BY FARMERS OF THE NORFOLK DISTRICT.

To ascertain the preferences of local farmers for the different classes of soils in growing the more important truck crops, a series of circular letters was sent out. The more important facts in the replies to these letters are discussed below.

Potatoes.—Replies were received from 32 growers who reported upon a total acreage of 1,636 acres. Twenty-five growers, or 78 per cent of those reporting, express a preference for sandy loam soils for potatoes, while the remaining 7, or 22 per cent, prefer a loam. In several instances distinction is made between the crop grown for extra early market and that for later harvesting. In all cases the sandy loam soils are preferred for the early crop. The yields reported by these 32 growers range from 30 barrels per acre to a maximum of

S-8248

FIG. 1.—CABBAGE ON KEYPORT FINE SANDY LOAM, NEAR PORTSMOUTH, VA.

S-3474

FIG. 2.—CORN AND COWPEAS, FOLLOWING EARLY POTATOES, ON NORFOLK FINE SANDY LOAM, NEAR CHURCHLAND, VA.

S-8492

FIG. 1.—VOLUNTEER HAY (CRABGRASS), FOLLOWING EARLY CROPS OF POTATOES OR CABBAGE, NEAR CHURCHLAND, VA.

S-8265

FIG. 2.—PLANTING COWPEAS AS A SUMMER GREEN-MANURING CROP, AFTER EARLY CABBAGE, ON NORFOLK FINE SANDY LOAM. CEDAR HEDGE AS A WINDBREAK, NEAR CHURCHLAND, VA.

S-8226

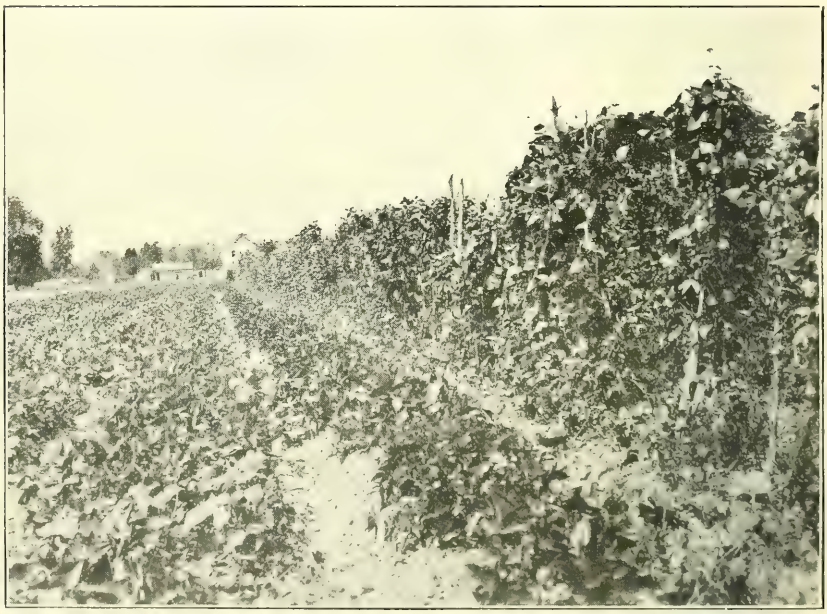
FIG. 1.—PICKING STRAWBERRIES ON SASSAFRAS COARSE SANDY LOAM AND NORFOLK LOAM, NEAR DIAMOND SPRINGS, VA.

S-8232

FIG. 2.—PACKING STRAWBERRIES GROWN ON SASSAFRAS FINE SANDY LOAM, NEAR DIAMOND SPRINGS, VA.

S-8259

FIG. 1.—PICKING SNAP BEANS ON NORFOLK FINE SANDY LOAM, NEAR CHURCHLAND, VA.



S-8459

FIG. 2.—BUSH AND POLE LIMA BEANS ON NORFOLK GRAVELLY LOAM, DIAMOND SPRINGS AREA, VA.

S-8444

FIG. 1.—SPINACH, ON THE SASSAFRAS FINE SANDY LOAM, NEAR DIAMOND SPRINGS, VA.

S-9517

FIG. 2.—KALE, ON THE NORFOLK FINE SANDY LOAM, NEAR CHURCHLAND, VA.

100 barrels. The estimated mean production is about 60 barrels. It must be remembered that the spring crop is harvested to bring the largest cash return per acre and that this is accomplished by digging a part of the crop at an early date to obtain the higher prices, while the rest of the crop, harvested at a later date, produces a larger yield per acre, but is sold at a lower price. Thus, the 30-barrel yields represent chiefly the earliest digging, while the larger yields result from permitting the crop to come more nearly to maturity. Under the system practiced in the Norfolk district, it is evident that, within reasonable limits, yield per acre is affected chiefly by the date of harvest.

The methods of management employed with the potato crop are evidently very uniform in the district. The early crop of potatoes is usually followed by a summer crop. In many cases volunteer grass, chiefly crab grass, is permitted to occupy the land and later harvested for forage. In other cases the land is occupied immediately after the harvesting of the potatoes by a crop of corn or by corn with cowpeas or soy beans sown in alternate rows. Following the harvest of the summer crop, either a winter truck crop is planted or, in some cases, rye and crimson clover are used as winter cover crops. The common practice, however, is to follow potatoes with a summer forage crop and then use the land for a winter truck crop.

Fertilization for the potato crop is practically standardized in the Norfolk district. Under normal conditions a commercial fertilizer, analyzing 7 per cent of ammonia, 6 per cent of phosphoric acid, and 5 per cent of potash, is used at the rate of 1,200 to 2,000 pounds per acre. During the shortage of potash salts caused by the war the practice was to increase the amount of phosphoric acid. A common formula being 7 per cent ammonia and 8 or 9 per cent phosphoric acid with no potash or, in a few instances where it could be obtained, 1 to 3 per cent potash.

Stable manure is used for the potato crop, so far as it is obtainable. It is chiefly purchased from local sources of rather limited supply. (See Pl. XI, figs. 1 and 2.)

Careful cultivation of the potato crop is the rule in the Norfolk district. Poisons are applied to control the potato beetle and some of the more progressive farmers spray with Bordeaux mixture to counteract the blight.

It should be noted that the Norfolk district produces the Irish Cobbler almost exclusively for the spring crop of potatoes, and grows a relatively small acreage of "Peach Blow" potatoes as a fall crop.

Cabbage.—Replies were received from 19 growers, representing a total of 242 acres of cabbage. Five of the replies, or 26 per cent of those reporting, indicate a preference for a sandy loam soil for cabbage

growing; 12 growers, or 63 per cent of the number answering, prefer a loam soil; and 2 growers, or 10 per cent, prefer a clay soil for cabbage production.

The yields of cabbage reported range from 100 to 250 barrels per acre, with an indicated mean production of about 200 barrels.

There is considerable diversity in the methods of management of the cabbage crop in the Norfolk district. To an appreciable extent cabbage is planted along the shoulders of the spinach beds as soon as the greater part of that crop has been harvested. Some growers plant cabbage upon land from which a summer crop of corn or hay has been harvested. Others follow various short rotations.

Usually there is no interval in which to grow a green-manuring crop in preparation for cabbage.

The most common method of fertilization for cabbage is to use a moderate application of the fertilizer commonly employed for potatoes at the time of transplanting the cabbage. This is followed at intervals through the winter and early spring by applications of a fertilizer analyzing 10 per cent of ammonia, 5 to 7 per cent of phosphoric acid, and 2 or 3 per cent of potash.

The more soluble sources of ammonia are used in the winter fertilizers, as the crop is subject to cool conditions under which the surface soil may be frozen for short periods. The total applications of commercial fertilizer for cabbage range from 500 to 2,000 pounds per acre with a mean of about 1,500 pounds. Stable manure is used if available.

The earliest spring crop of cabbage is handled with special reference to the promotion of growth during the winter and spring. The crop is set as spinach is removed and a high ridge is plowed up on the northern side of the cabbage row for the purpose of protecting the young plants from cold winds and to intercept and reflect the sunlight. Later in the season the ridge is worked down and the winter applications of fertilizer are made. The crop thus handled is available for early shipment. This early crop is set only upon the best drained and warmest soils, chiefly the coarse and fine sandy loams of the district. A later crop is planted on the heavier soils or those not quite so well drained naturally. Thus the cabbage crop may be grown on quite a variety of soils, ranging from the best drained members of the Sassafras and Norfolk series, used for the early crop, to the dark sandy loams and loams of the Suffolk and Portsmouth series, which give a large yield at a somewhat later date in the spring.

Strawberries.—The replies of 20 growers, representing 304 acres of strawberries, show no decided preference in the selection of soils for this crop. Seven prefer a sandy loam, 7 a loam soil, and 6 a heavy loam or clay soil. This is in general accord with the observations in the district. It is probable that strawberries are grown

upon a wider range of soil types than any other important crop in the Norfolk section.

The yields reported range from 35 to 75 crates, of 32 quarts each, per acre, with a mean of about 60 crates.

Strawberries are usually set in the late winter or early spring, the plants being obtained from established beds. During the first year it is a rather common practice to interplant either beans, peas, or potatoes in the new beds. The cultivation and fertilization of the berries suffice for these crops and some use is made of the land while the new bed is becoming established.

Usually no opportunity is afforded in this system for the turning under of a green manuring crop. Stable manure is used to a rather small extent.

The use of commercial fertilizer on strawberries and the accompanying crops is general. From 500 to 2,000 pounds per acre is applied, both the amount and the mixture used varying considerably. Not infrequently the formula is chosen with regard to the accompanying crop. The 7–6–5 formula, used for potatoes, or the 10–5–3 formula, used for winter forcing, is commonly applied to strawberries at different stages of their growth.

The earliest crops of berries are generally picked from the coarse sandy loam and the fine sandy loam types. Later crops are obtained from the dark sandy loam and the loam soils of the Suffolk and Portsmouth series. In some cases the best drained and earliest truck soils upon the individual farm are used for the winter and early spring truck crops, while strawberries, which occupy the land for two years, are set on heavier and later soils, where they will not interfere with the short rotations used for the other crops grown.

This explains in part why strawberries are grown under a wider range of soil conditions than any other crop in the district.

Beans.—Snap or string beans are an important crop in the Norfolk trucking district both in spring and in fall. Replies from 18 growers were received, representing 154 acres of beans. Four of the replies indicate a preference for a distinctly sandy soil and 10 for a sandy loam soil. Three prefer a loam and one a clay loam. Twenty-two per cent desire a sand and 55 per cent a sandy loam soil; thus 77 per cent of the answers indicate a choice of a well-drained, warm soil for this crop.

Snap beans are marketed chiefly in half-barrel hampers or baskets. The yields reported range from 50 to 200 baskets per acre, with a mean of 100 to 150 baskets.

A considerable part of this crop is grown as an interplanting with new strawberry beds, but a large acreage is also grown alone, especially in the spring. The fertilization of the crop consequently varies. In general, commercial fertilizer is applied at a rate of 500

to 1,000 pounds per acre. The formula varies, but either the usual potato fertilizer or that applied for winter forcing is most commonly employed.

Peas.—Garden peas are chiefly grown as a spring crop. Eleven replies to inquiries were received representing 83 acres of this crop. Eight growers prefer either a sandy soil or a sandy loam for peas, while three express a preference for a loam. As in the case of beans, over 70 per cent of the replies call for a warm, well-drained soil.

Peas are marketed in bushel baskets, and the replies show a range in yield of 30 to 80 baskets per acre, with a normal production of about 50 baskets.

Peas are also grown as an interplanted crop to a considerable extent and are fertilized with reference to the accompanying crop. The amounts of commercial fertilizer range from 300 to 400 pounds to 1,000 pounds per acre.

Cucumbers.—Cucumbers are grown both as a field crop and under frames. (See Pl. XII, figs. 1 and 2.) The methods of management differ very markedly in the two cases. The producers growing the crop under frames require a light sandy soil, and all the manuring and fertilizing is on an intensified scale. As much as 50 to 60 tons of stable manure per acre may be used for the forcing crop, together with heavy applications of soluble fertilizers. After the earliest part of the crop is harvested and all danger of frost is over, the frames are removed and the vines are allowed to spread, producing a later crop. The yields from this form of production are heavy and not at all comparable with those of the field crop.

The 16 replies concerning the cucumber crop were chiefly from those producing the field crop. Thirteen growers, or 80 per cent, prefer either a sandy soil or a sandy loam for the crop. Three are in favor of a loam soil.

The yields under field conditions range from 50 to 150 barrels per acre, with a mean of about 100 barrels.

In practically all cases stable manure is used in considerable amounts. In addition commercial fertilizers are used at a rate of 500 to 1,500 pounds per acre, with a normal application of about 1,000 pounds.

Sweet potatoes.—Of the 15 replies received from growers of sweet potatoes, 13, or 87 per cent, state a preference for a sandy soil or a sandy loam for this crop.

While sweet potatoes are rather a subordinate crop in the Norfolk district, a considerable acreage is grown, especially at points where marketing facilities are not quite so favorable as to permit of the more intensive forms of truck growing. Usually the individual acreages within the trucking district are small.

The reports indicate an average yield of 60 to 70 barrels per acre. Manure is quite generally used for this crop, with a supplementary application of 500 to 1,000 pounds of commercial fertilizer. The formula employed varies, ranging from a mixture analyzing 2–8–6 to the 7–6–5 formula commonly used on Irish potatoes.

Cantaloupes.—Only six replies were received with respect to cantaloupes, but it is notable that all indicate a preference for a sandy or sandy loam soil.

Watermelons.—Five replies with respect to watermelons; all express a preference for a sandy soil.

Spinach.—Replies were received from 17 growers, representing a total of 559 acres of spinach. Seven, or 41 per cent, prefer a sandy loam soil; 6, or 35 per cent, prefer a loam; and 4 growers, or 24 per cent, prefer a heavy loam or clay.

The yields reported range from 50 to 400 barrels per acre, with a mean of about 200 barrels.

Spinach is the most extensively grown of the strictly winter truck crops. There is some variation in the methods of production, although the greater part of the acreage follows a summer forage crop, either volunteer hay or a crop of corn or of corn and cowpeas.

The land is plowed, harrowed, and thrown up into narrow, flat-topped beds early in the fall and the spinach seeded while there is time for a strong growth before the colder winter weather sets in.

Stable manure, so far as it can be obtained, is used for the crop, but the chief dependence is placed upon commercial fertilizers. These are applied at the rate of 1,000 to 2,000 pounds per acre, the most common application being 1,000 to 1,200 pounds. A part of the application is made just before seeding, but additional applications are made during the winter whenever warm weather permits. The fertilizer used for this winter crop usually contains 10 per cent of ammonia, derived from soluble sources, from 4 to 8 per cent of phosphoric acid, and 2 to 4 per cent of potash.

It is coming to be a common practice in the Norfolk district to apply from 500 to 1,000 pounds of lime in some form, at the time the spinach beds are prepared.

Kale.—Kale is second only to spinach in the Norfolk district as a winter truck crop. Replies were received from 15 growers, representing 177 acres of kale. Of these, 3, or 20 per cent, prefer a sandy loam soil; 11, or 73 per cent, express preference for a loam soil; and 1 prefers a clay soil.

The yields reported range from 200 to 300 barrels per acre, with an average of about 250 barrels.

Kale is most commonly planted after a summer crop of volunteer hay or after corn. The planting is made in the early fall and the crop makes the greater part of its growth early in the season. The

harvest begins in December and cutting is continued through the winter.

Stable manure is used for the crop of kale to such an extent as it can be obtained. Commercial fertilizer is applied to an aggregate amount of 1,000 to 2,000 pounds per acre. About 500 pounds is applied at the time of planting and additional top dressings are made during the winter months. The first application is frequently of the common formula for potatoes, 7–6–5, while the winter mixture consists of the more soluble goods, also used for cabbage and spinach.

The preferences expressed by growers for certain classes of land for growing the particular truck crops are summarized in Table VIII.

TABLE VIII.—*Soil preferences expressed by farmers.*

Crop.	Number of replies.	Sand.		Sandy loam.		Loam.		Clay.	
		Number.	Per cent.	Number.	Per cent.	Number.	Per cent.	Number.	Per cent.
Watermelon	5	5	100.0						
Cantaloupe	6	1	17.0	5	83.0				
Sweet potato	15	3	20.0	10	67.0	2	13.0		
Cucumber	16	3	20.0	10	60.0	3	20.0		
Peas	11	2	18.0	6	55.0	3	27.0		
Potatoes	32			25	78.0	7	22.0		
Beans	17	4	22.0	10	55.0	3	17.0	1	6.0
Spinach	17			7	41.0	6	35.0	4	24.0
Strawberries	20			7	35.0	7	35.0	6	30.0
Cabbage	19			5	26.0	12	63.0	2	10.0
Kale	15			3	20.0	11	73.0	1	7.0

Although the number of replies received was too small to give a decisive answer to the question of local soil preferences for the different truck crops, yet the grouping of the preferences is rather significant.

GENERAL CONCLUSIONS.

The study of the Norfolk trucking district indicates very clearly that the different classes of farming and the production of the different crops are closely related to the differences in drainage conditions which exist within the district.

These drainage conditions are controlled by (a) location with respect to the natural outlets, (b) the altitude and slope of the land surface, and (c) the texture or relative porosity of the soil and subsoil. The classification of the soils of the district is closely related to these features.

The soils of the Sassafras and Norfolk series are relatively well drained. They lie chiefly in positions near the natural drainage outlets, along the shore line and the larger tidewater embayments, They occupy positions of some elevation above water level. They vary in texture to a considerable extent, and this variation, which establishes the individual soil type, exerts a considerable influence

upon the utilization of the different soils of these series for the growing of crops.

The soils of the Keyport and Suffolk series are not naturally well drained. They occupy flat upland areas at some distance from the more pronounced drainage channels. They are chiefly of fine-grained texture, ranging from fine sandy loam to loam and silt loam. Only areas where artificial drainage has been installed are well suited to the production of truck crops. Other areas are used for growing forage crops or else remain in forest.

The soils of the Portsmouth series are naturally poorly drained, large tracts remaining in a semiswampy condition. They are chiefly found in depressed and level areas in positions around stream heads or remote from the deeper-cut stream ways. They are chiefly forested. Where artificial drainage has been established they are used for the growing of forage crops and of some truck crops.

The detailed studies of the relationships between soil types and crops indicate a selection of certain soils for specific crop uses.

The Sassafras coarse sandy loam, occurring on low elevations and ridges, is esteemed as a year-round trucking soil. Two-thirds of its area within the limits of the surveys is cleared and over one-half is used for truck crops, both winter and spring. Strawberries lead in acreage. Spinach is the most important winter truck crop on this type. Important areas of cabbage, early potatoes, and snap beans are also encountered. The total area of the type in the Norfolk district is of rather limited extent.

The Sassafras fine sandy loam, occurring on level or gently sloping uplands, near the deeper stream ways, is a highly prized soil for truck crop production. Approximately two-thirds of its area is under cultivation. For spring truck crops over one-half of its area is utilized, and in summer and fall about 36 per cent of its area is used for trucking. Potatoes and cucumbers are the most important spring crops; spinach and kale lead among winter crops. Cabbage and a spring crop of snap beans are also grown. The area given to strawberries within the limits of these surveys is small.

The Sassafras loam is of limited extent within the surveys and in the general district. It occurs on level areas near well-established drainage ways. Because of this position it is chiefly cleared and used for the growing of truck crops. Two-thirds of its area is thus utilized in both fall and spring. Strawberries lead in acreage, while cabbage and potatoes are important spring crops. Spinach is the chief winter truck crop, occupying more than one-half of the area of the type.

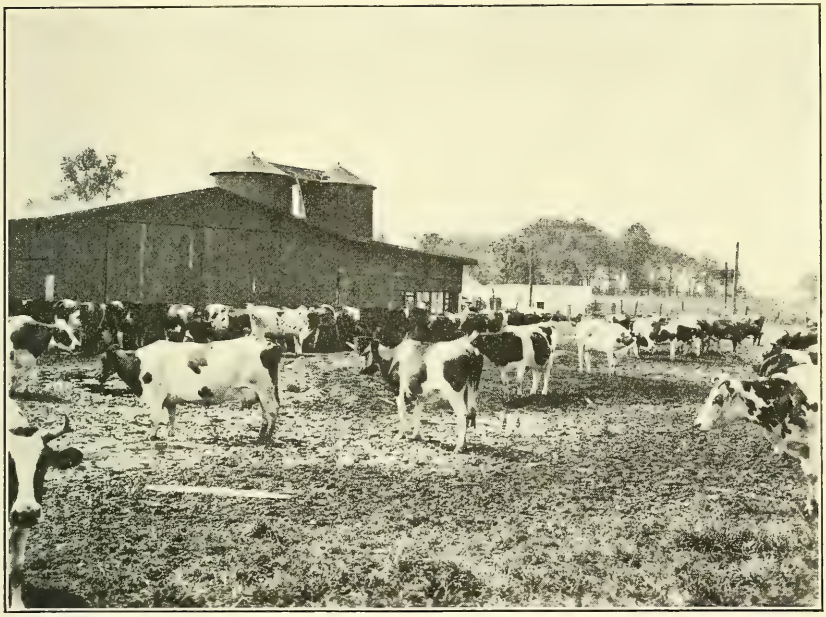
The Norfolk coarse sandy loam, found on low ridges and gentle upland slopes, is a preferred soil for trucking purposes. Over 70 per cent of its area is cleared and almost entirely occupied for the growing

of truck crops. Strawberries lead in acreage within the area mapped. Potatoes and cabbage are the other important spring crops; spinach leads among winter crops. Kale is grown to a small extent.

The Norfolk fine sandy loam is the most important trucking soil encountered in the surveys or in the district. It occurs chiefly upon level, well-drained uplands, contiguous to tidewater. Within the limits of the detailed surveys, over 90 per cent of its area is under cultivation. In the spring practically all of this area is used for truck crop production. In the late summer and early fall, forage crops occupy rather more than one-half its extent. Potatoes are the most important spring truck crop on the Norfolk fine sandy loam, occupying 58.6 per cent of the part of the type included in the detailed survey. It is safe to say that they constitute at least one-half of the spring truck crop acreage on the type throughout the Norfolk district. Cabbage is second in importance, covering 10 per cent of the area surveyed. Snap beans and strawberries cover the other important areas. Among fall and winter truck crops, kale is by far the most important on the Norfolk fine sandy loam in the Churchland area and it is extensively grown on the type in the district. Fall crops of potatoes and spinach are next in importance.

Norfolk loam, extensively developed within the limits of the Diamond Springs area and in the general district, is usually found upon level uplands or slight ridges and is moderately well drained in its natural condition. Within the limits of the detailed survey less than one-third of its area is cleared and commonly used for crop production. Over 40 per cent is in forest or cut-over land, and a considerable part of the land once cleared is not regularly used for cropping. In the general district it is probable that a somewhat larger proportion of the type is regularly tilled, chiefly to general farm crops. Within the area surveyed about one-half of the cropped area is occupied by forage crops and one-half by truck crops. Among these, strawberries are of greatest extent, and small areas of cabbage, potatoes, and spinach are also grown. Corn, either grown alone or with cowpeas interplanted, is the most important forage crop. Corn, cowpeas, winter oats, sorghum, and even cotton are produced on this type within the district

The Norfolk gravelly loam is of small extent, either in the areas surveyed or in the district as a whole. It occurs as small areas chiefly associated with the Norfolk loam. About one-half of its area in the Diamond Springs area is cleared and cropped. This is greater than the normal proportion. The type is not desired as truck soil and its chief use for such purposes is made by colored farmers. Lima beans, strawberries, early potatoes, and some spinach are grown. Corn is the most important forage crop, occupying the largest area of any of the crops grown.

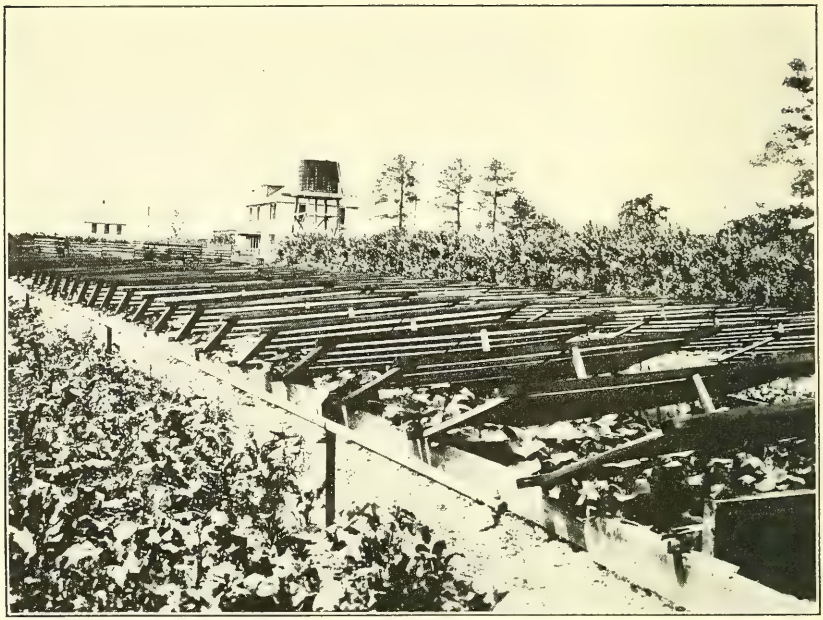


S-8530

FIG. 1.—DAIRY FARMING ON THE SUFFOLK LOAM, NEAR NORFOLK, VA. THE HEAVIER SOIL TYPES ARE USED FOR FORAGE CROP PRODUCTION.

S-8462

FIG. 2.—STABLE MANURE, USED FOR TRUCK GROWING, NEAR CHURCHLAND, VA.



S-8241

FIG. 1.—EARLY CUCUMBERS, GROWN UNDER SASH, ON NORFOLK FINE SANDY LOAM, NEAR PORTSMOUTH, VA.

S-8353

FIG. 2.—FIELD CROP OF CUCUMBERS ON SUFFOLK FINE SANDY LOAM, NEAR CHURCHLAND, VA.

The Keyport fine sandy loam occupies a moderate area in the Churchland survey. It is found to some extent throughout the Norfolk district in moderately drained localities on the level upland usually somewhat remote from the main drainage ways. It is available for trucking when artificially drained and is used for growing general farm crops or remains in forest when not so improved. In the area surveyed the type has all been underdrained by tile and is occupied nearly to its extent by various crops. Over 95 per cent of its area is in truck in the spring. Potatoes are the most important crop grown, covering nearly 59 per cent of the soil. Cabbage is second in importance. Cucumbers, snap beans, and strawberries are the other crops grown. In the late summer and fall two-thirds of the type is occupied by forage or green-manuring crops. Volunteer hay and corn, either alone or with cowpeas and soy beans, are chiefly grown. Kale is the most important winter truck crop. Fall potatoes, spinach, and a fall crop of beans are also grown.

The Suffolk fine sandy loam is of rather small area in the region. It is not naturally well drained and occupies level to slightly depressed areas. Underdrainage is requisite to render it available for trucking. In the Churchland area it has been drained and three-fourths of its extent is used for spring truck crops. Potatoes are the leading crop, occupying nearly one-half of its area. Cabbage is important. Snap beans, strawberries, and cucumbers are also gown on the type. Kale is the only fall crop grown extensively on it. It carries a high percentage of corn and volunteer hay as summer crops.

The Suffolk loam is of small extent within the areas mapped, but occupies much larger areas to the south of the trucking district. It is naturally poorly drained, occupying level tracts at some distance from the more pronounced stream ways. In general it is either forested or occupied chiefly for the growing of forage crops. Only about one-third of the area mapped as this soil is cleared and cultivated. This area is about equally divided between general farm crops and a variety of truck crops, chiefly strawberries, grown by colored farmers.

The Suffolk gravelly loam is an unimportant type in the district. It is poorly drained and chiefly in forest. The cleared area mapped is used by colored farmers for growing forage crops and truck crops.

No important areas of soils of the Portsmouth series are included within the two detailed surveys. In general the Portsmouth sandy loam, fine sandy loam, and loam occupy extensive tracts somewhat to the south of the region of intensive truck farming. They are poorly drained naturally and chiefly remain in forest. Small areas within the trucking district and larger areas where drainage has been established have proved to be of considerable value for the growing of certain truck crops. The spring crop of potatoes, straw-

berries, and cabbage are the most important crops grown. The summer and fall crops are chiefly corn or corn and cowpeas. There is abundant evidence that the Portsmouth sandy loam and fine sandy loam are well suited to potato growing when good drainage can be provided. Large crops are obtained at nearly as early a date as upon the fine sandy loams of better natural drainage.

It is thus apparent from a study of the soils of the Norfolk trucking district that fine sandy loam soils dominate in total extent and are the preferred soils for truck-crop production. The Norfolk fine sandy loam is the most important trucking soil. Upon it the greater part of the early Irish potato crop is grown. It is an important cabbage soil. Strawberries are successfully grown. Snap beans, peas, cucumbers, radishes, beets, and cauliflower are also grown. It is used in summer for egg plant, tomatoes, and cantaloupes. It carries a large acreage of kale and spinach in the winter months.

The Sassafras fine sandy loam is of much less extent, but is also a highly prized trucking soil. Its crop uses do not differ materially from those of the Norfolk fine sandy loam.

The coarse sandy loams are of decidedly smaller extent than the fine sandy loams in the district. They are very fully occupied for truck crop production, especially for the growing of the winter crops of spinach and kale. Strawberries cover the largest acreage in the areas mapped, but this is not held to be the general rule. Potatoes are not grown on either the Norfolk or Sassafras coarse sandy loam to as great extent as upon the fine sandy loams. Cabbage and snap beans are important crops.

The loam soils differ with respect to truck-crop production. The small areas of well-drained Sassafras loam are occupied nearly to their full extent for the growing of strawberries, cabbage, and spinach. The Norfolk loam, not usually well drained, is largely forested or used for the growing of general farm crops. Strawberries, potatoes, cabbage, and spinach are successfully grown on the best-drained parts of the type.

The gravelly loams are of very limited extent in the district and are not esteemed for trucking.

Large areas of the soils of the Keyport, Suffolk, and Portsmouth series remain in forest. Well-located areas, either drained or capable of drainage, are available for truck-crop production, especially for growing potatoes, strawberries, and cabbage.

Limitations in drainage, caused by position and soil texture, chiefly control the distribution of truck-crop production in the Norfolk district and strongly influence the distribution of the various crops upon the well-drained and moderately drained types of soils.

THE EASTERN SHORE TRUCKING DISTRICT OF VIRGINIA.

LOCATION.

The two counties of Accomac and Northampton in Virginia, located between Chesapeake Bay and the Atlantic Ocean, are commonly designated as the Eastern Shore of Virginia. This section comprises a total land area of 682 square miles or 436,480 acres. It is bounded on the north and northwest by Worcester and Somerset Counties, Md., on the east by the Atlantic Ocean, and on the west by Chesapeake Bay and its tributaries.

The production of truck crops, and of forage and general farm crops grown in conjunction with such crops, constitutes the chief agricultural industry of these counties. The magnitude of the trucking industry is shown by the statistics of truck-crop production for the section. The following estimate of shipments of various truck crops is furnished by the Eastern Shore of Virginia Produce Exchange. It is probable that total shipments exceed even these totals, since some independent marketing of produce occurs.

TABLE IX.—*Production of truck crops in Accomac and Northampton Counties, Va., 1911 to 1916, inclusive.*[1]

Year.	Irish potatoes.	Sweet potatoes.	Onions.	Strawberries.	Cabbage.
	Bushels.	*Bushels.*	*Hampers.*[2]	*Crates.*[3]	*Crates.*[4]
1911	2,403,838	1,845,990	44,733	30,616	48,109
1912	4,598,170	2,874,231	89,828	81,508	48,727
1913	7,649,510	3,525,368	97,252	49,356	84,188
1914	7,083,664	2,281,623	65,095	45,778	110,395
1915	7,839,492	2,367,040	201,488	58,991	88,666
1916	7,719,249	3,736,983	69,156	48,610	90,156

[1] From Soil Survey of Accomac and Northampton Counties, Va., E. H. Stevens, Field Operations, Bureau of Soils, 1917.
[2] Hamper = five-eighths bushels.
[3] Strawberry crate = 32 quarts.
[4] Cabbage crate = two-thirds barrel, or 2 bushels. Some cabbage is also shipped in barrels.

Assuming moderate yields per acre for each of these crops, it is probable that the two counties plant annually about 65,000 to 70,000 acres to potatoes, 20,000 to 25,000 acres to sweet potatoes, around 1,000 acres to strawberries, and about 500 acres each to onions and cabbage. These estimates probably are somewhat below rather than above the total plantings. Small areas of beans, cantaloupes, and watermelons are also grown.

The total area of improved land in farms shown for the two counties by the census of 1910 is 128,775 acres. The area in truck crops, as estimated, ranges from 87,000 to 97,000 acres, or somewhere between 67 and 75 per cent of the total improved land. Few trucking areas show such a high percentage of truck-crop occupation as this, and few of them exceed the Eastern Shore in total area given to the growing of truck crops.

Stevens, in the Soil Survey of Accomac and Northampton Counties, Va., calls attention to the progressive change from the growing of general farm crops to the production of truck crops on page 17 of his report.

It should also be remembered that there is rather less duplication of acreage in truck-crop production in these two counties than in other localities. The potato crop is commonly followed by corn or some other forage crop; sweet potatoes require the use of the ground for the entire growing season; strawberries occupy the land for two years or more, and only onions are marketed at a sufficiently early date to permit of duplication of trucking area.

CLIMATE.

Climatic records for this important trucking area are rather scanty. Records for Norfolk, Va., Wachaprague, Va., and Pocomoke City, Md., indicate a well-distributed rainfall ranging from 49.5 inches at Norfolk, and 39.6 at Pocomoke City, to 34.3 inches at Wachaprague, which lies between the two and within the area under discussion. The heaviest rainfall occurs during the growing season and is so well distributed that severe droughts are uncommon. The mean annual temperature for the two counties is about 57° F. with long, warm summers and only brief spells of severe weather during the prevalently mild winters.

The frost data for the three stations indicate a frost-free season of 230 days at Norfolk, 219 days at Wachaprague within the area, and 185 days at Pocomoke City inland and north of the section. It is probable that over the greater part of the Eastern Shore counties of Virginia the growing season is approximately 220 days.

The influence of the large bodies of water so nearly surrounding these counties is strongly felt in the equalization of climatic conditions. Summer heat is decreased by cool sea breezes, the cold of winter is tempered by the proximity of large bodies of relatively warm water, and the seasonal extremes of heat and cold are reduced. This influence of adjacent water bodies is especially pronounced in the narrow lower extremity of Northampton County, where tidewater is nowhere at a greater distance than 3 or 4 miles from the farms farthest inland. Consequently the growing season is appreciably longer from the vicinity of Eastville southward, than in the more northern part of the section. The same influence is noticed with respect to farms situated along the coast lines of both counties as contrasted with those lying in the interior.

Some localization of truck-crop production and certain differences in farm practice result from these local differences in climatic conditions.

TRANSPORTATION AND MARKETS.

The growth and development of the trucking industry on Eastern Shore of Virginia, as elsewhere along the Atlantic coast been to a high degree dependent upon the facilities afforded fo marketing of crops. The earlier agriculture of the region wa pendent upon shipment by water from points, principally on c tributary to Chesapeake Bay, which afforded steamboat comm cation. The crops grown under these conditions were chiefly staple farm crops which would stand storage and gradual marke With the building of the railroad in 1884 along the approximate of these two counties, rapid transit facilities were provided fo shipment of perishable commodities. The growing of truck had already been begun in a limited way, but the expansion decidedly rapid after rail transportation was provided. At present time few farms within the two counties are located at a tance of more than 5 miles from either rail or steamboat transp tion and the great majority of the farms are within easy hauling tance of some shipping point.

The New York, Philadelphia, & Norfolk Railroad and its nections afford access to all of the metropolitan markets of the and northeast. The distances from Cape Charles to Philadel and New York, respectively, are 220 and 310 miles. In additi frequent steamboat service connects Chesapeake Bay points Baltimore in 12 to 18 hours from the time of departure. Thu points in the two counties are well served by transportation.

The market outlets for the majority of shipments of truck from the Eastern Shore of Virginia are found in Philadelphia, York, Boston, and the other great cities of the Northeastern St although shipments are also made to points farther west and n even to the Canadian Provinces, when market conditions justi

An important factor in the marketing of truck crops from two counties is the association of farmers known as the Eastern S of Virginia Produce Exchange. This corporation, formed by truckers, possesses a central organization which keeps close t with the acreages and probable dates of shipment of the various c maintains a wire service for the collection and distribution of m information, and establishes grades and brands for the produce also standardizes grading, handles directly a considerable propo of the marketing and collections, and offers facilities for local sal certain products, notably strawberries. This cooperative associ of truck growers has tended to stabilize conditions not only from to time during the shipping season, but also, through its inform concerning reserve stocks and probable market conditions, from to year. Consequently, the Eastern Shore of Virginia counties shown steady, healthy growth in this industry.

AGRICULTURAL POPULATION.

The white population of the Eastern Shore is almost exclusively of English descent. The region was settled during the first third of the 17th century by English colonists, and their descendants comprise the greater part of the present population. In addition, there is a considerable negro population, chiefly engaged in farm labor.

The region possesses no large cities but is closely dotted with small towns and villages on the water courses and along the railroad. Manufacturing is of decidedly subordinate importance, agriculture and fisheries dominating the industry of the locality. It may almost be said that every inhabitant of the two counties is more or less directly interested in agriculture, as the secondary employments largely contribute in some form to the conduct of agricultural operations.

PHYSICAL FEATURES.

The Eastern Shore of Virginia is a long, low peninsula, extending southward from the Maryland line for a distance of 75 miles to the extremity at Cape Charles. The highest elevations within the area do not exceed 50 feet, while the greater part of the area lies at altitudes between 35 feet and actual tide level. In spite of these narrow ranges in altitude, there are several rather distinct divisions of surface.

The coast line along the Atlantic Ocean consists of a series of long, narrow islands forming a barrier between the ocean and the continuous mainland. These islands are occupied by ranges and masses of sand dunes, with marshes and glades. They are usually separated from the mainland by broad stretches of salt marsh or by shallow tidewater lagoons or by both. In some cases the sand-dune area abuts directly upon the mainland.

The greater part of the Chesapeake Bay foreland is formed by long, narrow peninsulas or "river necks," separated by winding estuaries or embayments. The land areas are usually flat topped and of low altitude. Several large and small islands of low elevation fringe this shore. Along the southern end of this border there are also present some sand-dune areas, particularly from Cape Charles City southward.

A similar but not very distinct zone of low forelands borders the larger estuaries and tidal embayments of the central portion of the eastern coast line.

The remainder of the mainland consists of a nearly level to gently undulating upland, relieved only by low ridges, which range from a few yards to 500 or 600 feet in width. The eastern and western borders of this upland are roughly marked by the courses of the Seaside and Bayside highways, respectively. Topographically there is an escarpment of gentle slope and low elevation which is marked on the western side and obscure or even lacking on the eastern border of this upland.

The more elevated ridges are irregular in their direction, and in many places include poorly drained or even marshy basin-shaped depressions. The ridges, themselves, are commonly rather sandy and are the best drained areas of the two counties. Some of the ridges show evidences of a slight accumulation of wind-blown sand, but the majority, together with the intervening hollows or levels, probably represent irregularities of the ancient sea bottom.

Over the greater part of the upland erosion is very slight. It is only in the extreme northeastern part of Accomac County, where the higher elevations occur near the coast line, that streams have cut their channels pronouncedly and that the slope of their channels is marked. Elsewhere the level or basin-shaped stream-heads on the divides are drained by tortuous streams of indistinct channels which become more marked and less swampy as the heads of the tidewater estuaries, into which they usually flow, are approached.

Drainage is moderately established over the central upland. It is frequently poorly established in the central portions of the broader river necks. It is best along the shoulders of the descents to tidewater channels and along the low inland ridges. Drainage is excessive in the sand-dune areas and almost absolutely lacking in the majority of the tidal marsh areas. A part of the land area along the Chesapeake Bay shore line lies so near to tide level that extra high tides, accompanied by strong winds, drive tide water over areas which are normally land surfaces.

The differences in these natural drainage conditions exert a controlling influence on the character of the soils of the Eastern Shore of Virginia and consequently upon the degree and kind of agricultural development which has taken place.

SOILS.

Five principal soil series are encountered in the Eastern Shore counties of Virginia. They are all of common occurrence in the more northern portions of the Atlantic Coastal Plain and are found to a considerable extent throughout the Maryland-Delaware-Virginia Peninsula. These are the Sassafras, Norfolk, Keyport, Elkton, and Portsmouth series of soils. In addition there are areas of tidal marsh, fresh-water swamp, and dune sand, none of which, in their present condition, are agricultural soils.

The characteristics of the soils of the Sassafras, Norfolk, Keyport, and Portsmouth series have already been described in connection with the Churchland and Diamond Springs districts. The Sassafras series is represented on the Eastern Shore by four types, the Sassafras sandy loam, fine sandy loam, loamy sand, and loam. The Norfolk fine sand is the only representative of that series and it is of small extent and importance. The Keyport sandy loam, fine sandy

loam, and loam were mapped in the two counties. The Portsmouth series is represented to a limited extent by the sandy loam and the loam.

Soils of the Elkton series are rather widely distributed in these two counties, as well as elsewhere on the Peninsula. The surface soils of this series are gray to ash-colored; the subsoils are pale gray, mottled with yellow and rusty brown stains. The subsoil is usually underlain by gray, sandy material, frequently saturated with water. The subsoil is usually compact and stiff but not especially plastic. Three types, the Elkton sandy loam, fine sandy loam, and loam were encountered in the soil survey of Accomac and Northampton Counties. Some areas of fresh-water swamp also occur.

The tidal marsh areas do not form an integral part of the agricultural upland area.

The dune sand is too coarse textured to retain sufficient moisture for the needs of ordinary agricultural crops, and it does not contribute to the tilled area of the section.

Among these different soils drainage and its consequent modifications of soil characteristics constitute the most important distinctions, controlling the extent and kind of agricultural occupation to a marked degree.

The Norfolk fine sand and the soils of the Sassafras series are the best drained agricultural soils of the region. They are generally cleared and occupied for some form of cropping. The soils of the Keyport series are fairly well drained and, by the use of open farm ditches, are rendered suitable for the production of the majority of crops common to the latitude. The soils of the Elkton series always require supplementary drainage to suit them to cropping, and even then their crop uses are somewhat restricted. They are not so extensively tilled as soils of the preceding series. The soils of the Portsmouth series are swampy or semiswampy in their natural condition, and, as yet, only small areas have been provided with adequate artificial drainage and brought under cultivation. Such areas as have been improved are usually included within areas of more valuable soils. The tidal marsh and swamp are undrained and utilized to only a small extent for pasture. Dune sand is of little agricultural value.

DETAILED CROP AND SOIL MAP.

Onley Area.

To make a detailed study of the characteristic agricultural soils of the Eastern Shore of Virginia counties, particularly with respect to their uses for truck crop production, a soil and crop survey of a small area around Onley in Accomac County was undertaken in 1916. This detailed survey covers 1,777 acres, or approximately 2¾ square

miles. It is centrally located on the crest of the broad, low divide within the main upland of the county and is crossed from northeast to southwest by the line of the New York, Philadelphia & Norfolk Railroad. The altitude of the railroad station at Onley is given as 44 feet above tide level.

The surface of the area is but slightly relieved. The greatest differences of elevation are not more than 15 to 20 feet, and there are no steep slopes within the area except for a short distance along both banks of the small creek which drains the area and leaves its limits near the southeastern corner.

Holding in mind that the extreme relief is but slight, the surface conditions may best be described as a low, broad rim of well-drained land, occupying the outer margins of the area, and a broad, flat, and slightly depressed basin which occupies the center of the survey immediately to the south of Onley and comprises the headwater basin of a small stream. It is not quite coextensive with the forested area shown to the south of Onley. Smaller depressions of a few acres in extent occur along the northeastern border of the survey.

Drainage is well established over all of the low ridge, but is not complete either in the larger or smaller basins, although artificial means to remedy this condition have recently been undertaken.

The distribution of the soils of the area closely follows these main features of drainage. The Sassafras sandy loam occupies the crest of the broad, low ridge; the Keyport sandy loam covers the more elevated level tracts; the Elkton sandy loam occupies the lower portions of the slopes to the basins and the greater part of those depressions; the Elkton loam is found in small patches in the centers of the basin areas; and the Portsmouth sandy loam occurs chiefly along the stream courses.

SOILS.

These five distinct soil types are developed in the area, although only three of them are of sufficient extent to be of agricultural importance. The following table shows their absolute and relative areas within the limits of the detailed map.

TABLE X.—*Areas of various soils in Onley area.*

Soil.	Acres.	Per cent.
Sassafras sandy loam	774.0	43.6
Keyport sandy loam	477.6	26.9
Elkton sandy loam	468.0	26.3
Elkton loam	20.4	1.1
Portsmouth sandy loam	37.4	2.1
Total	1,777.4	100.0

Sassafras sandy loam.—The surface soil of the Sassafras sandy loam, to a depth ranging from 8 to 15 inches, is a brown to grayish-brown medium sandy loam. The average depth of the surface soil in the Onley area is about 8 or 9 inches. It is slightly greater on level areas or on gentle slopes and somewhat less on the crests of low ridges. In the latter position the color is likely to be a pale yellowish brown and the soil in this situation contains a somewhat larger proportion of medium to rather coarse sand. Elsewhere the surface soil is somewhat loamy. The subsoil from about 9 inches in depth to 30 inches is a sticky reddish-brown sandy loam, containing a moderate amount of medium and fine sand and a rather high percentage of silt, together with some clay. It is retentive of moisture and of fertilizers. The deep subsoil from 30 inches to several feet in depth consists of an orange to reddish-brown loamy sand which sometimes contains a considerable quantity of fine gravel.

This important soil type occupies the higher elevations consisting of broad, low ridges, well-drained tracts of level land, and the particularly well-drained banks of streams which have cut below the level of the surrounding land. The texture of the soil, the presence of the sandy underlying layer, and the favorable location of the type have given rise to good natural drainage conditions. The reddish-brown to orange color of the subsoil furnishes a good indication that drainage has been and is excellent. The weathering of the included iron-bearing minerals has proceeded to an advanced stage and the material shows good aeration and drainage from the surface to a depth of more than 3 feet.

There are few or no slopes within the limits of the type which would interfere with cultivation, and erosion is not a problem on the Sassafras sandy loam either in the Onley area or anywhere within the borders of the Eastern Shore of Virginia counties. A slight amount of shifting of surface materials under wind action occurs over the highest crests of some of the low ridges unless they are well protected by vegetation, either growing crops or stalks. The effect of such movement is relatively unimportant.

The Sassafras sandy loam is the best drained, earliest, and warmest soil type suited to agricultural uses within the region. It is sought as the most desirable arable land, and the greater part of its area has been cleared and placed under cultivation. The chief exceptions consist of small forested areas and farm woodlots reserved for domestic use. In the Onley area 76.7 per cent of the Sassafras sand loam is occupied for some form of farm use, and only 23.3 per cent remains in forest. This proportion is about typical of the region as a whole.

Keyport sandy loam.—The surface soil of the Keyport sandy loam, to an average depth of 9 inches and ranging in depth to 12 inches, is

a grayish-brown sandy loam. The coloration of a freshly plowed field will vary from yellowish gray to gray and grayish brown, the latter color predominating. The immediate subsoil is usually a pale-yellow to grayish heavy sandy loam, in places faintly mottled in gray and yellow colors. Below a depth of 24 inches the subsoil is a mottled gray, yellow, and ocherous-brown sandy loam, which passes at about 36 inches into a grayish-yellow loamy sand.

The Keyport sandy loam is found over nearly level upland tracts and along the lower parts of gentle slopes, commonly intervening between more elevated areas occupied by the Sassafras sandy loam and the depressions occupied by soils of the Elkton series.

The texture of soil and subsoil is favorable to the establishment of drainage, but the position of the type and its altitude give rise to some accumulation of excess moisture by seepage from higher lying areas, while outlets are not well enough established to permit of the rapid removal of water at all seasons. The soil is moderately well drained in its natural condition and is usually capable of complete drainage with a minimum expense for ditching. Many crops may be grown upon the larger areas of this type without artificial drainage. For the earlier truck crops it should be ditched and tiled. Erosion occurs rarely within the limits of this type.

The Keyport sandy loam is a good general purpose soil and its best drained areas are also well suited to the growing of Irish potatoes and cabbage. It has been extensively cleared and occupied throughout these two Eastern Shore counties, and the survey of the Onley area shows that 67 per cent of its extent is utilized for some form of agricultural occupation, while only 33 per cent remains in forest. This is possibly a little higher percentage in cultivation than is common in the region.

Elkton sandy loam.—The surface soil of the Elkton sandy loam consists of 8 or 9 inches of gray to brownish-gray sandy loam, which appears pale gray to almost white when thoroughly dried out. It is rather coherent and has a tendency to form clods when tilled in a moist condition. The subsoil to a depth of 30 inches is a gray sandy loam, mottled with yellow and ocherous stains. The main body color is distinctly gray as distinguished from the prevailing yellow of the Keyport sandy loam. Below 30 inches the deep subsoil is a somewhat sticky gray sand, mottled with yellow. The deep subsoil is frequently moist to saturated.

The Elkton sandy loam occupies broad depressed areas having a level to slightly sloping surface. The type is found around the headwaters of streams and in small depressions within areas of the Keyport and Sassafras sandy loams. It also includes some small areas of more loamy material in small patches, usually less than an acre in extent.

The natural drainage of the Elkton sandy loam is interrupted and poor. Unless artificial drainage is resorted to, water stands upon the surface during parts of the winter and spring months and the type is slow to warm up in the spring even where some ditching has been provided. It is capable of drainage at a moderate cost over the larger areas, but some of the small depressions occupied by this soil are so completely surrounded by areas of other types, lying on low ridges, that the cutting of effective outlets to a sufficient depth is rather expensive. Consequently the larger areas are more frequently ditched than smaller areas, whose reclamation would scarcely repay the expense.

The texture of the soil is favorable to drainage operations and only topographic difficulties interfere with its more complete occupation. Drained areas of the type prove it to be a strong forage crop soil, and that certain of the late truck crops may be grown to advantage. The general condition of the type is well shown in the Onley area, where 59.0 per cent of its area remains in forest, although it is well located with respect to shipping facilities and there are no insurmountable obstacles to its drainage. The type, here and elsewhere on the eastern shore of Virginia, constitutes a valuable reserve of land which may be brought under cultivation by the establishment of community and farm drainage systems.

Elkton loam.—The Elkton loam consists of 6 to 10 inches of gray to light-brown silty loam, containing enough fine and medium sand to render it granular. The subsoil, to a depth of 24 inches, is a mottled gray and pale-yellow silty loam, rather compact and sticky. The deep subsoil is a mottled gray and yellow sandy loam which is usually moist and may be saturated.

The type is found in the Onley area in a few small, saucer-shaped depressions associated with the Elkton sandy loam and the Keyport sandy loam. It marks an accumulation of silty earth and of organic matter in the lowest parts of these depressions. It is poorly drained and of limited extent and importance. It is usually tilled in conjunction with other and better drained types and its uses in this area are not at all characteristic of the type. Where possible, it should be used for growing forage crops or late truck crops. Drainage would greatly improve its condition and, wherever the area concerned is large enough to justify the expense, should be supplied.

Portsmouth sandy loam.—The surface soil of the Portsmouth sandy loam, to a depth ranging from 5 to 15 inches, is a dark-gray to black sandy loam. A considerable quantity of partly decayed organic matter is visibly present. The subsoil is a gray sandy loam, sometimes faintly mottled with yellow, rusty stains. At a depth of about 30 inches, a gray, sticky sand is found. It is usually saturated.

The Portsmouth sandy loam occurs only along stream beds in the Onley area. It is either overflowed at times of heavy rain or is saturated with seepage water. It is not capable of drainage over the greater part of its extent, except by deepening and straightening of stream channels. It is of small extent and, at present, of little agricultural importance, being chiefly forested.

The important agricultural soils of the area are the Sassafras sandy loam, Keyport sandy loam, and Elkton sandy loam. Some small areas of Elkton loam attain to a most unusual agricultural use from their close association with these types.

It is because these types are characteristically found in the vicinity of Onley that the area was selected for detailed study. It is considered certain that the conditions found on the three main types within this area are rather closely representative of the general conditions under which they occur and are farmed throughout Accomac and Northampton Counties. This is evident from a comparison of the section with the detailed soil survey of the two counties.[3]

USES OF SOILS.

A detailed soil map and two crop maps were made of the Onley area to show the boundaries and extent of each distinct type of soil and to make possible the measurement of the areas of each different crop or form of occupation for each soil type. One crop map shows the normal crop distribution in July, when the maximum acreage of distinctly truck crops is to be encountered in this region. The other crop map shows the crop areas in September, after the main Irish potato crop has been harvested and typical fall conditions exist. If a third map showing conditions in the spring had been made it would probably show somewhat larger areas of such crops as cabbage, onions, and, possibly, strawberries, but the two maps presented give an idea of the more common uses of the different soils for cropping and of the relative importance of the different principal crops. They also indicate in a pronounced way some of the characteristics of crop rotation and double cropping which are common in the region.

Tables XI and XII show the absolute and relative importance of the different soil types and their uses for crop production.

[3] Soil Survey of Accomac and Northampton Counties, Virginia, E. H. Stevens, Field Operations, Bureau of Soils, 1917.

TABLE XI.—*Proportion of total area and of the area of each soil type occupied by various crops and groups of crops, Onley, Va., July, 1916.*

Crop and group of crops.	All soils.		Sassafras sandy loam.		Keyport sandy loam.	
	Acres.	Per cent.	Acres.	Per cent.	Acres.	Per cent.
General farm crops	205.4	11.6	91.0	11.8	71.4	15.0
Hay and pasture	46.4	2.6	24.2	3.2	19.6	4.1
Corn	113.4	6.4	55.8	7.2	32.0	6.7
Cowpeas	41.0	2.3	7.2	.9	19.0	4.0
Sorghum	3.2	.2	2.4	.3	.8	.2
Oats	1.4	.1	1.4	.2		
Truck crops	783.2	44.1	438.8	56.4	226.0	47.3
Potatoes	410.0	23.1	236.0	30.4	128.0	26.8
Sweet potatoes	287.6	16.2	173.4	22.4	70.0	14.7
Strawberries	58.4	3.3	13.2	1.7	20.0	4.2
Onions	23.2	1.3	10.6	1.4	7.6	1.6
All other vegetables	4.0	.2	3.6	.5	.4	
No annual crops	788.8	44.3	246.2	31.8	180.2	37.7
Forest	655.4	36.8	180.2	23.3	158.0	33.1
Gardens and grounds	117.2	6.6	55.2	7.1	19.0	4.0
No crop	9.8	.6	7.8	1.0	1.2	.2
Orchard	6.4	.3	3.0	.4	2.0	.4
Grand total	1,777.4		774.0		477.6	

Crop and group of crops.	Elkton sandy loam.		Elkton loam.		Portsmouth sandy loam.	
	Acres.	Per cent.	Acres.	Per cent.	Acres.	Per cent.
General farm crops	40.0	8.5	1.6	7.8	1.4	3.7
Hay and pasture	1.2	.2	.8	3.9	.6	1.6
Corn	24.0	5.1	.8	3.9	.8	2.1
Cowpeas	14.8	3.2				
Truck crops	106.8	22.8	12.4	60.8	1.2	3.2
Potatoes	42.0	9.0	3.4	16.7	.6	1.6
Sweet potatoes	38.2	8.2	6.0	29.4		
Strawberries	21.6	4.6	3.0	14.7	.6	1.6
Onions	5.0	1.0				
No annual crops	321.2	68.7	6.4	31.4	34.8	93.1
Forest	276.0	59.0	6.4	31.4	34.8	93.1
Gardens and grounds	43.0	9.2				
No crop	.8	.2				
Orchard	1.4	.3				
Grand total	468.0		20.4		37.4	

TABLE XII.—*Proportion of the total area and of the area of each soil type occupied by various crops and groups of crops, Onley, Va., September, 1916.*

Crop and group of crops.	All soils.		Sassafras sandy loam.		Keyport sandy loam.	
	Acres.	Per cent.	Acres.	Per cent.	Acres.	Per cent.
General farm crops	546.5	30.8	297.8	38.5	171.2	35.9
Hay and pasture	43.8	2.5	27.6	3.6	14.0	3.0
Corn	381.8	21.5	224.0	29.0	118.0	24.7
Corn and clover	3.8	.2	.4		3.4	.7
Corn and cowpeas	77.5	4.4	33.0	4.3	23.2	4.9
Cowpeas	32.4	1.8	11.0	1.4	7.4	1.6
Millet and cowpeas	3.8	.2	.8	.1	3.0	.6
Sudan and cowpeas	2.0	.1			1.8	.3
Sorghum	1.4	.1	1.0	.1	.4	.1
Truck crops	426.0	24.0	226.2	29.2	116.0	24.3
Potatoes	71.0	4.0	32.8	4.3	19.2	4.0
Sweet potatoes	287.2	16.2	173.2	22.4	70.8	14.9
Strawberries	62.4	3.5	15.8	2.0	25.0	5.2
All other vegetables	5.4	.3	4.4	.5	1.0	.2
No annual crops	804.4	45.2	250.0	32.3	189.8	39.8
Forest	655.4	36.8	180.2	23.3	158.0	33.1
Gardens and grounds	127.4	7.2	55.8	7.2	28.6	6.0
No crop	13.8	.8	9.6	1.3	1.2	.3
Orchard	7.8	.4	4.4	.5	2.0	.4
Grand total	1,776.9		774.0		477.0	

TABLE XII.—*Proportion of the total area and of the area of each soil type occupied by various crops and groups of crops, Onley, Va., September, 1916*—Continued.

Crop and group of crops.	Elkton sandy loam.		Elkton loam.		Portsmouth sandy loam.	
	Acres.	Per cent.	Acres.	Per cent.	Acres.	Per cent.
General farm crops	73.3	15.7	2.2	10.8	2.0	5.4
Hay and pasture	1.6	.3			.6	1.6
Corn	36.2	7.7	2.2	10.8	1.4	3.8
Corn and cowpeas	21.3	4.7				
Cowpeas	14.0	3.0				
Sudan and cowpeas	.2					
Truck crops	74.4	15.9	8.8	43.1	.6	1.6
Potatoes	18.0	3.8	1.0	4.9		
Sweet potatoes	37.2	8.0	6.0	29.4		
Strawberries	19.2	4.1	1.8	8.8	.6	1.6
No annual crops	320.4	68.4	9.4	46.1	34.8	93.0
Forest	276.0	59.0	6.4	31.4	34.8	93.0
Gardens and grounds	43.0	9.1				
No crop			3.0	14.7		
Orchard	1.4	.3				
Grand total	468.1		20.4		37.4	

SOIL AND CROP ACREAGES FOR JULY.

It will be noted from the tables that the absolute acreage of each crop or other form of land occupation is given for the entire area and for each soil type in detail. There is also shown the relative extent of occupation in each case in the form of percentages of the entire area or of the particular soil type. The percentage figures for the entire area establish a basis for comparison for all soils of the locality. It is thus possible to study any departures from the normal practice and to compare the uses of any particular soil for the growing of individual crops or groups of crops.

The July crop map shows a total area of 783.2 acres given to truck crops, or 44.1 per cent of the entire area. Almost an exactly equal area, 788.8 acres, or 44.3 per cent, is occupied by forest and homesteads or is not cropped. The remainder, 205.4 acres, or only 11.6 per cent of the area, is used for the growing of forage crops or for pasture. The most extensive single form of land occupation is that of forest, which covers 655.4 acres, or 36.8 per cent of the area mapped. The greater part of this forest land consists of the Elkton sandy loam and Portsmouth sandy loam, the latter type being forested to 93.1 per cent of its extent. The Sassafras sandy loam has only 23.3 per cent of its area in forest. Excluding the Elkton loam, a total area of 20.4 acres, the other types are relatively cleared and occupied in a degree closely comparable with their natural drainage conditions.

The July table shows the relative importance of the different crops grown. The area in Irish potatoes, amounting to 410 acres, constitutes 23.1 per cent of the total area and 41.5 per cent of the area in annual crops. Sweet potatoes occupy 287.6 acres or 16.2 per cent of the surveyed area, or 29.1 per cent of the cropped area. Corn,

covering 113.4 acres; strawberries, 58.4 acres, and cowpeas, 41 acres, are the other important crops. It will be noted that the area occupied by gardens and grounds is greater than the area given to corn in the early summer months.

The distinctive features of the area as a whole are found to be:

1. The occupation of 55 per cent of the total area for cropping.
2. The occupation of 80 per cent of the total cropped area by truck crops, while the general farm crops cover but 20 per cent.
3. The fact that Irish and sweet potatoes include 71.6 per cent of the entire cropped area.

These facts are closely representative of the general conditions in Accomac County. The relative importance of sweet potatoes is greater and that of Irish potatoes is somewhat less than in Northampton County.

A comparison of the acreage figures for the different crops on the individual soil types with those for the entire area provides a basis for the study of the selective use of different soils for different crops.

Sassafras sandy loam.—The Sassafras sandy loam bears annual crops to the extent of 68.2 per cent of its area, compared with 55.7 per cent for the entire area surveyed. Only 23.3 per cent remains in forest, compared with 36.8 per cent for the entire map. Irish potatoes occupy 30.4 per cent and sweet potatoes 22.4 per cent of its area, compared with 23.1 and 16.2 per cent for the total survey. Corn is also slightly in excess of the standard, as are onions and pasture. Other crops fall below the average. The type may thus be characterized as a preferred trucking soil, especially desired for growing the two most important crops of the region. (See Pl. XIII, figs. 1 and 2, and Pl. XIV, fig. 1.)

Keyport sandy loam.—The Keyport sandy loam bears annual crops to the extent of 62.3 per cent of its area, or slightly in excess of the standard. Irish potatoes occupy 26.8 per cent of its extent, a little above the normal; sweet potatoes fall a little below, with 14.7 per cent, as against 16.2 for all soils. Both the total area of truck crops and that of forage crops slightly exceed the normal for the area at the expense of forested lands and homestead areas. The type is evidently considered to be rather more favorable for the growing of Irish potatoes than of sweet potatoes. (See Pl. XIV, fig. 2, and Pl. XV, fig. 1.) A slight preference is given strawberries also.

Elkton sandy loam.—The Elkton sandy loam is distinguished by the forest occupation of 59 per cent of its area, while 22.8 per cent is given to truck crops and 8.5 per cent to general farm crops. All of the truck crops fall below the normal percentage for the region except strawberries, which cover 21.6 acres, or 4.6 per cent of its extent compared with a standard percentage of 3.3. The forage crops also fall below the normal, with the exception of cowpeas,

which are slightly above. It is evident that, in the local judgment, the Elkton sandy loam is not a good trucking soil except for strawberries and that it is not even highly esteemed for the growing of forage crops.

Elkton loam.—The Elkton loam is not typically occupied within the limits of the Onley survey. The small areas found lie within the limits of fields dominated by other soils and they are tilled in accordance with the requirements of the more important types. Hence, 68.6 per cent of the area of the type is cropped, an entirely unusual condition. Sweet potatoes are found on 29.4 per cent of its area, although this soil is not usually considered a good one for the crop. The presence of a rather high percentage of strawberries (Pl. XV, fig. 2) and of a relatively large area of corn and hay is more nearly in accordance with the local cropping practices on the Elkton loam. Generally, on the Eastern Shore of Virginia, the Elkton loam is rather extensively forested and the cleared areas are most commonly used for the growing of forage crops, especially such as can be planted well along into the summer season when the type has had an opportunity to dry out.

Portsmouth sandy loam.—The presence of forest on 93.1 per cent of the area of the Portsmouth sandy loam is characteristic of the region. Its adventitious use for the growing of hay, for pasture, and for small areas of Irish and sweet potatoes is in accord with the general treatment of the type elsewhere in the two Eastern Shore counties. This soil is not commonly cleared and utilized except as small areas of it occur within the limits of other soils better suited to the common cropping systems of the region.

Viewed from the standpoint of individual crops, the soil facts become even more striking. The following summary by crop areas and percentages brings out this relationship:

The Sassafras sandy loam comprises 774 acres or 43.6 per cent of the entire area of the survey. It carries the following acreages and percentages of leading crops:

	Acres.	Per cent of crop.
Irish potatoes	236.0	57.6
Sweet potatoes	173.4	60.3
Strawberries	13.2	22.6
Onions	10.6	41.4
Miscellaneous vegetables	3.6	90.0

The Keyport sandy loam occupies 477 acres or 26.9 per cent of the area. It carries the following acreages and percentages of leading crops:

	Acres.	Per cent of crop.
Irish potatoes	128.0	31.2
Sweet potatoes	70.0	24.4
Strawberries	20.0	34.2
Onions	7.6	32.8
Miscellaneous vegetables	0.4	10.0

The Elkton sandy loam covers 468 acres or 26.3 per cent of the area. It carries the following acreages and percentages of leading crops:

	Acres.	Per cent of crop.
Irish potatoes	42.0	10.2
Sweet potatoes	38.2	13.3
Strawberries	21.6	37.0
Onions	5.0	21.5

These crop relationships show clearly that the Sassafras sandy loam is preferred for growing Irish potatoes, is greatly preferred for the sweet potato crop, is about normal for growing onions, and is used for the production of the greater part of the miscellaneous vegetables.

The Keyport sandy loam is an approved Irish potato soil, is slightly discriminated against for sweet potato production, and is a preferred soil for strawberries and onions.

The Elkton sandy loam is discriminated against for both Irish and sweet potatoes, is a strongly preferred strawberry soil, and neither chosen nor avoided for onions.

No information regarding the cabbage crop and little regarding onion production can be obtained from this map. Cabbages are chiefly grown in the southern part of Northampton County. The largest acreage of onions is normally found in the vicinity of Onancock, Accomac County. Moreover, both crops are chiefly harvested at an earlier season than that of the Onley map. Stevens' survey of the two counties would indicate that the Sassafras sandy loam and fine sandy loam are known to be the types chosen for winter cabbage production and that both the Keyport sandy loam and the Sassafras sandy loam are used for onion growing.

SOIL AND CROP ACREAGES FOR SEPTEMBER.

Some very striking changes in crop occupation become evident when the crop map for July is compared with that for September. The area in forest remains the same, the area in orchard is slightly increased, as is also that not occupied at the time by annual crops.

The total cropped area changes little, since 54.8 per cent of the total area is still occupied by annual crops, but the distribution is quite different. The truck crops have been largely harvested, their area sinking to 24 per cent of the total, while forage crops increase to 30.8 per cent. There is no change in the relative importance of sweet potatoes, as digging begins in September. The acreage in Irish potatoes is only 71 acres, compared with 410 acres in July. The crop is almost entirely harvested between July and September and its place is taken by a fall crop of Irish potatoes, grown for seed, and by a greatly increased acreage of corn and of corn and cowpeas, planted together. A number of other forage crops in small acreage also appear.

These changes in total crop acreage for the different crops reflect the common cropping practices of the region. The early Irish potato crop is interplanted with corn, and the fields, just before digging the potatoes, constitute the "potato-corn" characteristic of Eastern Shore of Virginia potato growing. (See Pl. XVI, fig. 1.) After the potato crop is harvested, the corn occupies the land, and some growers also sow cowpeas or crimson clover between the rows of corn. (See Pl. XVI, fig. 2.) Other forage crops are grown to a small extent, as upon fields where onions or cabbage have been harvested. Some of the potato or onion land is set to new fields of strawberries and the berry fields which have reached the limit of profitable production are plowed out and either a forage crop is grown or the land is reset to berries.

These changes in crop occupation are very evenly distributed over the different soil types so that no special feature in fall cropping appears as distinct from the spring and summer conditions. The regularity of cropping systems and practices is strongly indicated by this fact.

SOIL PREFERENCES EXPRESSED BY FARMERS.

A series of circular letters was sent out to ascertain the preferences of farmers in different parts of the two counties for different classes of soils used in the growing of the important truck crops. From the replies received the more important facts concerning the different crops were tabulated.

It is evident that the reports from these representative growers, the evidence obtained by Stevens for his report on the Soils of Accomac and Northampton Counties, and the data obtained by means of the detailed soil and crop map of the Onley area, Virginia, are well in accord.

The salient points of soil preference, as given by the growers, are shown in Table XIII.

TABLE XIII.—*Classes of soils preferred by growers for various crops.*

Crop.	Sandy loam.		Loam.		Heavier.	
	Number.	Per cent.	Number.	Per cent.	Number.	Per cent.
Sweet potatoes	51	86.5	5	8.5	3	5.0
Onions	10	66.7	5	33.3		
Potatoes	41	58.6	28	40.0	1	1.4
Cabbage	6	30.0	14	70.0		

As in the case of the Norfolk district, the Eastern Shore growers show a progressive choice in soil textures for these crops. In both cases the more sandy soils, sandy loams, are preferred for sweet potatoes; both sandy loam and loam soils are desired for Irish

potatoes; while the loam soils are preferred decidedly for cabbage production.

In comparing these districts with those farther to the north, it should be held in mind that early marketing is a prime requisite for both the Norfolk and the Eastern Shore districts, so that a somewhat more sandy and early soil is desired for potato growing than in the case of the New Jersey areas. Even in that district there is a strong tendency to use the Sassafras sandy loam for growing Irish Cobblers and heavier soils for other and later varieties. The same type is the preferred Cobbler soil on the Eastern Shore, while fine sandy loams are preferred and more extensively used for growing the crop in the Norfolk district.

These well-drained and warm soils seem to combine earliness of maturity with moderate to high yields in the case of potatoes and to be the very best soils for truck crop potato growing in the Middle Atlantic Coast region.

Potatoes.—Seventy-one growers of potatoes reported 2,242 acres in this crop, or an average of 31.6 acres each. The most extensive grower reports 175 acres; the smallest, 1 acre. The acreages in the majority of cases are between 20 and 75 acres.

The reported yields of potatoes range from 35 to 110 barrels per acre, with the great majority of growers reporting 50 to 75 barrels. Many report yields of 80 to 100 barrels, and yields as large as this are undoubtedly obtained in numerous instances in both counties.

In the management of the potato crop the great majority of growers report the use of some winter cover crop on the land where potatoes are to be grown. The most common crop is rye, alone, or rye and crimson clover. Wheat also is used alone or with crimson clover or winter vetch. Oats are similarly used in some cases.

Stable manure is applied to potato ground, wherever obtainable, the home supply of manure being augmented in most cases by composting with pine needles, or "shatters," and with other forest litter. This practice is common in the two counties and woods refuse is so highly prized that nearly every farm retains a small woodlot within which the annual crop of pine needles and other refuse is carefully protected for use in composting with stable manure. (See Pl. XVII.)

The use of commercial fertilizer at the time these inquiries were made was greatly disturbed by war conditions, potash salts being practically unprocurable. The farmers were therefore asked to report the usual practice and any existing variations. From replies received it appears that the common formula for potato fertilizer is 7 per cent of ammonia, 6 per cent phosphoric acid, and 5 per cent potash, and that with a shortage of potash the proportion of

phosphoric acid is increased, a common mixture analyzing 7–6–0, 7–8–0, or in some cases 7–6–3. Extensive experiments with potato fertilizers within the two counties indicate strongly that this commonly used formula, 7–6–5, is best suited to the soils, crop rotations, and climatic conditions of the region. It is notable for the somewhat lower percentage of potash than in the formula used in more northern potato-growing regions. The large yields obtained on the Eastern Shore of Virginia abundantly justify this formula for the conditious existing there.

There is a wider variation in the amount of fertilizer applied per acre than in the formula used. The range, according to the replies received, is from 1,000 to 2,000 pounds per acre. By far the greater number of growers report either 1,200, 1,400, or 1,500 pounds per acre. Probably 1,400 pounds represents a fair average application in these two Eastern Shore counties.

Of 70 growers expressing opinion as to the proper soil texture for potato growing, 41 growers, or 58.6 per cent, prefer a sandy loam soil; 28 growers, or 40 per cent, prefer a loam soil, some stating that they prefer a dark loam; and only one prefers a clay loam. The distinct preference for a sandy loam soil is a very good reflection of the fact that the dominant soils of the region are of this class and it is in strict accord with the use of the Sassafras sandy loam, "red sandy loam," and the Keyport sandy loam, known as "dark loam," as shown by the detailed soil and crop map of the Onley area.

It should be noted that some extensive growers, who have drained some of the wetter and heavier soil types, find that under these conditions the heavier soils are well suited to growing a rather late crop but heavy yield of potatoes. The extension of potato growing on the Eastern Shore of Virginia will be made possible in part by such drainage and in part by the clearing of some of the forested areas of naturally better drained types. Both procedures are possible over extensive areas.

It should be said that the marked uniformity in farm practice in the growing of potatoes in this region is not due to chance. The experimental work of the Virginia Truck Experiment Station, with a branch farm at Tazely, the free interchange of experience which is made possible through the produce exchange, and the universality of the potato crop, which places practically every farmer in touch with his neighbors in the study of successful cropping practices, all tend to the rapid discarding of practices which do not prove to be profitable and to the adoption of a well-regulated use of crop rotations, cover crops, manures, and fertilizers, and a uniform method of cultivation and even of marketing the crop.

Thus the farm practice of the Eastern Shore of Virginia in growing potatoes has become practically standardized to include the following points:

For potato production use well-drained, sandy loam soils.

Grow a cover crop or green manuring crop on the land in the winter preceding the planting of potatoes—rye, wheat, or oats, and crimson clover preferred.

Use stable manure, composted with "shatters" and leaf mold, broadcasted over the field.

Apply, usually in the row, 1,200 to 1,500 pounds of a commercial fertilizer which, preferably, does not depart far from the standard formula of 7 per cent ammonia, 6 per cent phosphoric acid, and 5 per cent potash.

Cultivate clean and ridge up the crop.

Interplant corn in alternate middles before the crop blossoms.

Dig part of the crop early and allow the balance to come nearly to maturity.

Market the crop cooperatively.

These are the distinctive and common characteristics of Irish potato production in the two Eastern Shore counties of Virginia.

Sweet potatoes.—Replies were received from 62 growers of sweet potatoes, who report 810.5 acres. The individual acreage ranges from 1 to 72 acres, with the majority reporting from 5 to 20 acres. The average is about 13 acres for each grower reporting.

As in the case of Irish potatoes, the use of a cover crop in the rotation is almost universal. Rye or wheat and crimson clover predominate for this purpose. Manure is used wherever available, although a marked tendency to use the supply upon Irish potatoes is indicated.

The fertilizers used vary decidedly. The formulæ reported range from 2 to 7 per cent ammonia, from 5 to 11 per cent phosphoric acid, and from 0 to 10 per cent potash. The majority of the replies show that mixtures containing from 3 to 7 per cent ammonia, from 5 to 8 per cent phosphoric acid, and from 3 to 8 per cent potash are preferred. Some growers use the same formula as for Irish potatoes, but the majority use brands containing less ammonia.

The quantities applied also vary greatly, ranging from 300 to 1,400 pounds per acre, with the majority using from 500 to 800 pounds or considerably less than for Irish potatoes. The tendency of the plants to run to vines if large amounts of nitrogenous fertilizer are used is noted by some growers.

The reported yields of sweet potatoes range from 40 to 110 barrels per acre, the majority of the reports giving between 60 and 70 barrels.

The soil preferences are very definite. Fifty-one growers, or 86.5 per cent of all who express an opinion, prefer a sandy loam soil for the crop, five prefer a loam, and 3 some other class of soil.

It may be said that both the Sassafras and Keyport sandy loams are used for this crop. The former is generally preferred, but the latter may be used successfully, as it ordinarily dries out sufficiently

early to permit transplanting, and it is sufficiently well drained to produce a large yield of roots.

It is evident that the growing of sweet potatoes has not become as well standardized in this district as that of Irish potatoes. The crop is somewhat subordinate in importance, although coming to be grown more extensively. It fits in well with the growing of Irish potatoes and helps to distribute the employment of labor through the year. It can be recommended as a crop thoroughly well suited to the Sassafras sandy loam and to the better drained areas of the Keyport sandy loam.

Cabbage.—Only 22 answers were received with regard to the cabbage crop. These represent 72 acres, or an average of 3¼ acres for each grower. The acreage ranges from one-half acre to 12 acres each. The use of cover crops and manure is about the same as for potatoes.

The cabbage crop is a winter and early spring crop in this region and the fertilizer practice is adjusted to the cool growing conditions of the early part of the winter season. Growers use two different formulæ. The standard formula for application before transplanting, intended to carry the crop throughout the season, is almost uniformly the potato formula, 7–6–5. In addition, side dressings are made, during the colder months, of a mixture analyzing 10 per cent ammonia in some soluble form, 6 per cent phosphoric acid, and 5 per cent potash. The amount of fertilizer applied varies from 1,000 to 2,000 pounds per acre, with the majority of growers using about 1,500 pounds. Of this 1,000 pounds or more is of the 7–6–5 formula and 500 pounds or less contain the larger amount of soluble ammonia.

Fourteen growers, or 70 per cent, prefer a loamy soil for cabbage and 6 prefer a sandy loam soil. The yields reported range from 85 to 200 one-barrel crates per acre with an average production of about 150 barrels.

The cabbage crop is not sufficiently represented in the Onley area to afford verification of these expressed soil preferences, but they are well in accord with the general practice in cabbage growing.

Onions.—Sixteen growers report a total of 44 acres of onions. The individual areas range from 1 to 15 acres, the majority producing from 1 to 3 acres. The use of cover crops and manures preceding onions is general. The applications of fertilizer range from 500 to 1,700 pounds per acre, with 1,000 to 1,200 pounds predominating. The potato formula, 7–6–5, is dominant, although in the absence of potash several growers report the use of 7–8–0 or 5–8–0.

The reported yields range from 30 to 500 one-bushel crates, with an average of about 200 bushels per acre.

The onion crop is scarcely represented in the Onley area. It is grown more extensively in the vicinity of Onancock, where both the

Sassafras loam and fine sandy loam are used for onion culture. Of the 15 growers reporting, 10 prefer a sandy loam soil, and 5 a loam soil. For the early spring crop this preference is believed to be well founded.

RELATIONSHIP BETWEEN SPECIAL CROPS AND DEFINITE SOIL TYPES.

Table XIV summarizes the results of the surveys of the Churchland, Diamond Springs, and Onley areas for spring and summer crop conditions.

TABLE XIV.—*Proportion of total area and of the area of each soil type occupied by various crops and groups of crops: Churchland area, Va., June, 1916; Diamond Springs area, Va., June, 1916; Onley area, Va., July, 1916.*

Crop and group of crops.	All soils.		Sassafras coarse sandy loam.		Sassafras sandy loam.		Sassafras fine sandy loam.		Sassafras loam.		Norfolk coarse sandy loam.	
	Acres.	Per cent.	Acres.	Per cent.	Acres.	Per cent.	Acres.	Per cent.	Acres.	Per cent.	Acres.	Per cent.
General farm crops	455.6	9.6	29.1	10.5	91.0	11.8	41.8	12.1	2.5	2.4	13.5	4.6
Corn	309.4	6.5	26.4	9.5	55.8	7.2	30.3	8.8			10.9	3.7
Hay and pasture	61.2	1.3	2.7	1.0	24.2	3.2	2.2	.6			2.6	.9
Cowpeas	49.0	1.0			7.2	.9			2.5	2.4		
Wheat	15.1	.3					9.3	2.7				
Oats	10.7	.2			1.4	.2						
Soy beans	7.0	.2										
Sorghum	3.2	.1			2.4	.3						
Truck crops	2,400.0	50.4	152.6	54.8	436.8	56.4	178.2	51.8	69.3	67.3	198.8	68.3
Potatoes	1,135.6	23.9	12.7	4.5	236.0	30.4	97.1	28.2	4.8	4.7	63.2	21.7
Strawberries	394.7	8.3	100.3	36.1	13.2	1.7	6.2	1.8	24.4	23.7	80.0	27.6
Sweet potatoes	316.4	6.6	8.0	2.9	173.4	22.4			5.5	5.3	1.8	.6
Cabbage	260.8	5.5	16.9	6.0			18.9	5.5	22.7	22.0	50.6	17.4
Beans	123.8	2.6	10.0	3.6			12.3	3.6	3.6	3.5	1.5	.5
Cucumbers	70.2	1.5					27.7	8.1	.5	.5	.4	.1
All other vegetables	98.5	2.0	4.7	1.7	14.2	1.9	16.0	4.6	7.8	7.6	1.3	.4
No annual crop	1,903.8	40.0	96.5	34.7	246.2	31.8	124.2	36.1	31.1	30.2	78.8	27.1
Forest	1,273.3	26.8	58.2	21.0	180.2	23.3	45.6	13.3	11.8	11.5	56.4	19.4
No crop	360.1	7.6	21.8	7.8	7.8	1.0	42.7	12.4	16.7	16.2	10.2	3.5
Gardens and grounds	235.3	5.0	12.7	4.6	55.2	7.1	35.2	10.3	2.6	2.5	6.5	2.2
Orchard and vineyard	34.0	.6	3.8	1.3	3.0	.4	.7				5.7	2.0
Swamp	1.1	.0										
Grand total	4,759.4	100.0	278.2		774.0		344.2		102.9		291.1	

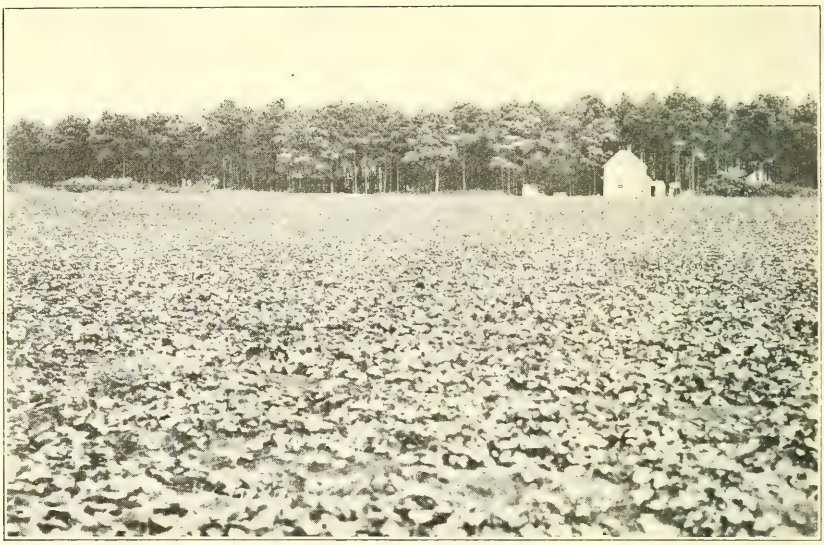
Crop and group of crops.	Norfolk fine sandy loam.		Norfolk loam.		Norfolk silt loam.		Norfolk fine sand.		Norfolk gravelly sandy loam.		Norfolk gravelly loam.	
	Acres.	Per cent.	Acres.	Per cent.	Acres.	Per cent.	Acres.	Per cent.	Acres.	Per cent.	Acres.	Per cent.
General farm crops	9.2	1.9	57.4	11.6					1.4	4.1	38.7	14.6
Corn	2.8	.6	44.0	8.9							32.8	12.4
Hay and pasture			4.0	.8					1.4	4.1		
Cowpeas											3.3	1.2
Wheat			5.8	1.2								
Oats			3.6	.7							2.6	1.0
Soy beans	6.4	1.3										
Truck crops	438.3	89.8	67.2	13.6			6.4	68.8	3.9	11.2	95.2	36.1
Potatoes	299.0	61.2	6.0	1.2			6.4	68.8	.2	.6	14.2	5.4
Strawberries	31.2	6.4	41.1	8.3					3.5	10.0	18.1	6.8
Sweet potatoes			1.5	.3							6.9	2.6
Cabbage	48.8	10.0	14.0	2.8					.2	.6	6.6	2.5
Beans	34.4	7.0	1.7	.4							25.1	9.5
Cucumbers	11.8	2.4	.4	.1							5.1	1.9
All other vegetables	13.1	2.8	2.5	.5							19.2	7.4
No annual crop	40.8	8.3	370.8	74.9	9.0	100.0	2.9	31.2	29.3	84.7	130.1	49.3
Forest	.8	.2	200.3	40.4					25.5	73.7	65.1	24.7
No crop	13.1	2.6	165.6	33.5	9.0	100.0	.7	7.5	1.8	5.2	41.9	15.9
Gardens and grounds	26.9	5.5	3.1	.6			2.2	23.7	.4	1.1	13.8	5.2
Orchard and vineyard			1.8	.4					1.6	4.7	9.3	3.5
Grand total	488.3		495.4		9.0		9.3		34.6		264.0	

S-8281

FIG. 1.—A GOOD CROP OF POTATOES ON SASSAFRAS SANDY LOAM, ACCOMAC COUNTY, VA.

S-8278

FIG. 2.—HARVESTING POTATOES ON SASSAFRAS SANDY LOAM, NEAR ONANCOCK, VA.



S-8399

FIG. 1.—SWEET POTATOES ON SASSAFRAS SANDY LOAM, NORTHAMPTON COUNTY, VA.

S-8288

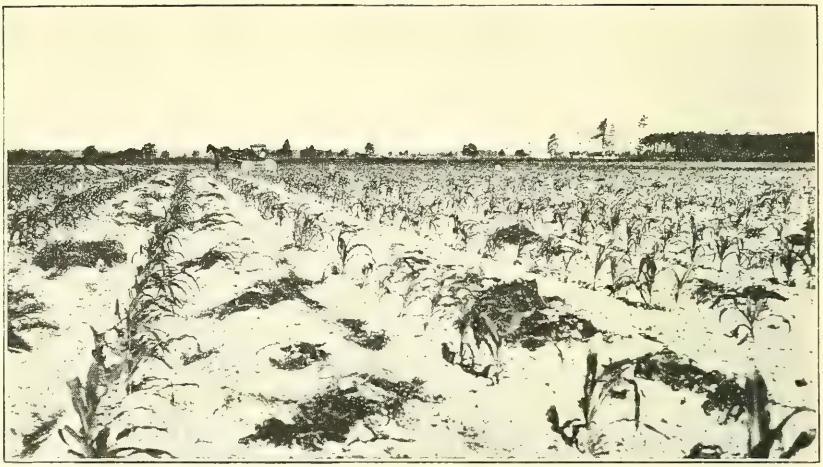
FIG. 2.—POTATOES (IRISH COBBLER) ON KEYPORT SANDY LOAM, ACCOMAC COUNTY, VA.

S-8505

FIG. 1.—HARVESTING SWEET POTATOES ON KEYPORT SANDY LOAM IN ACCOMAC COUNTY, VA.

S-8523

FIG. 2.—STRAWBERRIES ON ELKTON LOAM, NEAR ONLEY, VA.

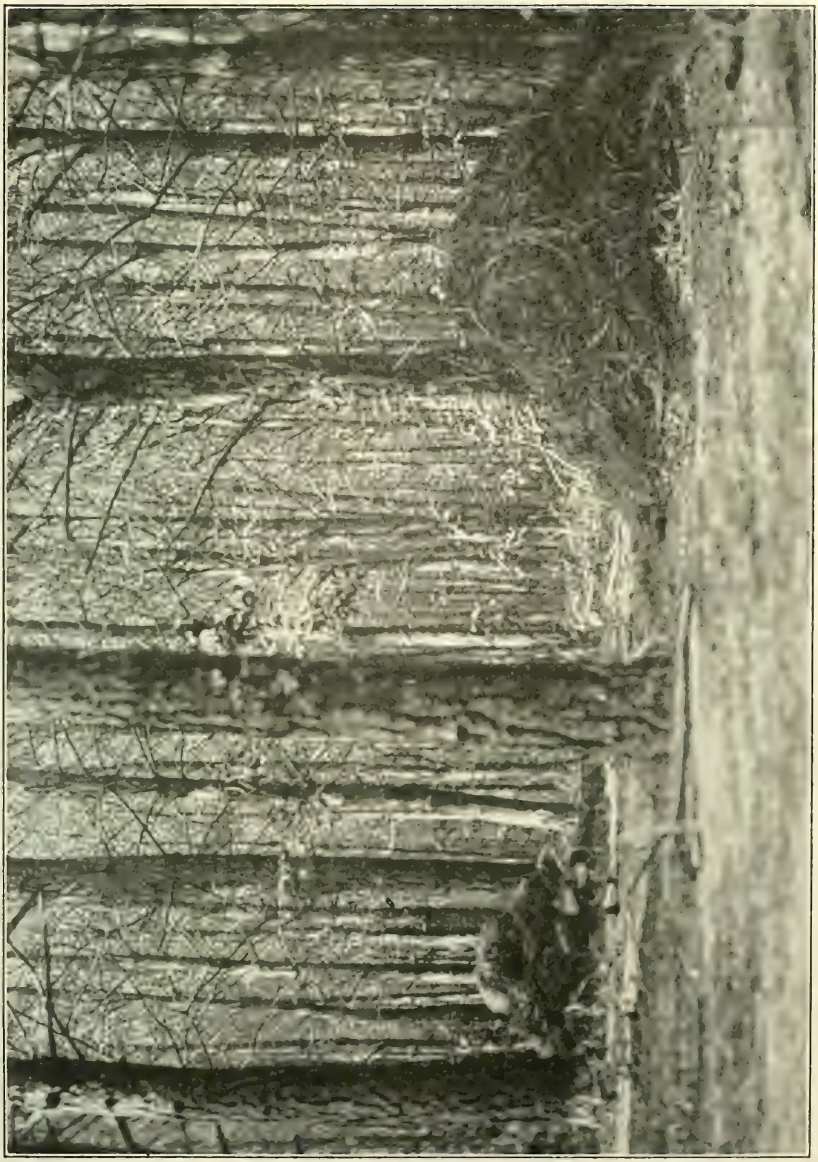


S-8418

FIG. 1.—"POTATO-CORN." IMMEDIATELY AFTER POTATO HARVEST. ON SASSAFRAS FINE SANDY LOAM, ACCOMAC COUNTY, VA.

S-8524

FIG. 2.—CORN AND COWPEAS ON SASSAFRAS SANDY LOAM, ACCOMAC COUNTY, VA.



S-862

PINE NEEDLES AND FOREST LITTER SAVED FOR COMPOSTING WITH STABLE MANURE. A COMMON PRACTICE IN EASTERN VIRGINIA.

TABLE XIV.—*Proportion of total area and of the area of each soil type occupied by various crops and groups of crops: Churchland area, Va., June, 1916; Diamond Springs area, Va., June, 1916; Onley area, Va., July, 1916*—Continued.

Crop and group of crops.	Keyport sandy loam.		Keyport fine sandy loam.		Elkton sandy loam.		Elkton loam.		Suffolk fine sandy loam.		Suffolk loam.	
	Acres.	Per cent.	Acres.	Per cent.	Acres.	Per cent.	Acres.	Per cent.	Acres.	Per cent.	Acres.	Per cent.
General farm crops	71.4	15.0	0.6	0.3	40.0	8.5	1.6	7.8	.....	.....	43.2	22.1
Corn	32.0	6.7	.....	.....	24.0	5.1	.8	3.9	.....	.....	39.7	20.3
Hay and pasture	19.6	4.1	.....	.....	1.2	.2	.8	3.9	.....	.....	1.5	.8
Cowpeas	19.0	4.0	.....	.....	14.8	3.2	.....	.....	.....	.....	1.8	.9
Oats	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.2	.1
Soy beans	.....	.....	.6	.3	.....	.....	.....	.....	.....	.....	.....	.....
Sorghum	.8	.2	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Truck crops	226.0	47.3	201.0	95.5	106.8	22.8	12.4	60.8	107.5	73.7	34.1	17.4
Potatoes	128.0	26.8	123.4	58.6	42.0	9.0	3.4	16.7	71.8	49.2	.9	.4
Strawberries	20.0	4.2	5.6	2.6	21.6	4.6	3.0	14.7	5.0	3.4	14.2	7.3
Sweet potatoes	70.0	14.7	.....	.....	38.2	8.2	6.0	29.4	.....	.....	1.6	.8
Cabbage	.....	.....	48.3	23.0	.....	.....	.....	.....	20.6	14.1	3.8	2.0
Beans	.....	.....	7.5	3.6	.....	.....	.....	.....	6.2	4.3	10.9	5.6
Cucumbers	.....	.....	15.3	7.3	.....	.....	.....	.....	3.9	2.6	.7	.3
All other vegetables	8.0	1.6	.9	.4	5.0	1.0	.....	.....	.....	.....	2.0	1.0
No annual crop	180.2	37.7	8.8	4.2	321.2	68.7	6.4	31.4	38.3	26.3	117.6	60.3
Forest	158.0	33.1	6.9	3.3	276.0	59.0	6.4	31.4	34.4	23.6	97.9	50.2
No crop	1.2	.2	.....	.....	.8	.2	.....	.....	1.1	.7	13.2	6.8
Gardens and grounds	19.0	4.0	1.9	.9	43.0	9.2	.....	.....	2.8	2.0	5.8	3.0
Orchard and vineyard	2.0	.4	.....	.....	1.4	.3	.....	.....	.....	.....	.7	.3
Grand total	477.6	.....	210.4	.....	468.0	.....	20.4	.....	145.8	.....	194.9	.....

Crop and group of crops.	Suffolk gravelly loam.		Portsmouth sandy loam.		Portsmouth loam.		Loamy sand.		Swamp.	
	Acres.	Per cent.	Acres.	Per cent.	Acres.	Per cent.	Acres.	Per cent.	Acres.	Per cent.
General farm crops	12.8	17.6	1.4	3.7	.....	.....	.....	.....	.....	.....
Corn	9.1	12.6	.8	2.1	.....	.....	.....	.....	.....	.....
Hay and pasture	.4	.5	.6	1.6	.....	.....	.....	.....	.....	.....
Cowpeas	.4	.5	.....	.....	.....	.....	.....	.....	.....	.....
Oats	2.9	4.0	.....	.....	.....	.....	.....	.....	.....	.....
Truck crops	30.1	41.7	1.2	3.2	9.9	83.9	24.3	95.7	.....	.....
Potatoes	3.1	4.3	.6	1.6	5.2	44.1	17.6	69.3	.....	.....
Strawberries	4.4	6.1	.6	1.6	1.9	16.1	.4	1.6	.....	.....
Sweet potatoes	3.5	4.8	.....	.....	.....	.....	.....	.....	.....	.....
Cabbage	3.1	4.3	.....	.....	2.4	20.3	3.9	15.3	.....	.....
Beans	8.7	12.0	.....	.....	.4	3.4	1.5	5.9	.....	.....
Cucumbers	4.4	6.1	.....	.....	.....	.....	.....	.....	.....	.....
All other vegetables	2.9	4.1	.....	.....	.....	.....	.9	3.6	.....	.....
No annual crop	29.3	40.7	34.8	93.1	1.9	16.1	1.1	4.3	4.5	100.0
Forest	14.2	19.7	34.8	93.1	.8	6.8	.....	.....	.....	.....
No crop	8.0	11.1	.....	.....	.....	.....	.....	.....	.....	.....
Gardens and grounds	3.1	4.3	.....	.....	.....	.....	1.1	4.3	.....	.....
Orchard and vineyard	4.0	5.6	.....	.....	.....	.....	.....	.....	.....	.....
Swamp	.....	.....	.....	.....	1.1	9.3	.....	.....	4.5	100.0
Grand total	72.2	.....	37.4	.....	11.8	.....	25.4	.....	4.5	.....

Truck crops occupy 50.4 per cent of the total land area included in the three surveys, general farm crops occupy 9.6 per cent, and 40 per cent of the area is not occupied by annual crops.

A considerable proportion of the entire area surveyed is thus not cropped, and it is desirable to compare crop acreages on the basis of their relationship to the cropped area as well as with respect to their proportionate place in the whole area.

It then appears that truck crops, which cover 50.4 per cent of the entire area, comprise 84 per cent of the cropped area.

Potatoes are the crop most extensively grown, occupying 23.9 per cent of the total and 39.7 per cent of the cropped area. They are the chief crop in both the Churchland and Onley areas, but in the Diamond Springs area are exceeded in acreage by strawberries, cabbage, and corn.

Strawberries are second in rank, occupying 8.3 per cent of the total and 13.8 per cent of the cropped area. They lead in acreage in the Diamond Springs area but are of decidedly secondary importance in both of the others.

Sweet potatoes cover 6.6 per cent of the entire area and 11.8 per cent of the cropped area. They are important only in the Onley area, are decidedly subordinate in the Diamond Springs area, and are not found in the Churchland area.

Cabbage occupies 5.5 per cent of the total area and 9.1 per cent of the cropped area. It is an important crop in the Churchland and Diamond Springs areas but practically lacking in the Onley area.

Beans are similarly confined to the Churchland and Diamond Springs areas. They occupy 2.6 per cent of the total area and 4.3 per cent of the cropped area. Owing to extensive interplanting of beans with other crops, this does not quite give the crop its true rank. Counting all areas of beans, those grown alone and interplanted with other crops, the percentages become 3 per cent of the entire area and 5 per cent of the cropped area.

Cucumbers, grown chiefly in the Churchland area and not at all in the Onley area, occupy 1.5 per cent of the areas mapped and 2.4 per cent of the cropped area.

All other vegetables cover 2 per cent of the total and 3.4 per cent of the cropped area.

It is evident that Irish potatoes constitute the most important truck crop in eastern Virginia, occupying 47.3 per cent of the entire acreage devoted to truck.

Corn is the only important general farm crop, covering 6.5 per cent of the total and 10.8 per cent of the cropped area. It is exceeded in area by potatoes, strawberries, and sweet potatoes. This condition is changed, however, when fall crop areas are examined, since corn, interplanted with the spring potato crop or following it, occupies 20 per cent of the total fall area and 33.6 per cent of the land then in crops. This constitutes one of the important features of the cropping of the region. It should be noted that each of the three surveys exhibits a good acreage of corn, either planted alone or with cowpeas or crimson clover. The Churchland area shows 264 acres; the Diamond Springs area, 225 acres; and the Onley area, 463 acres. Thus, at the proper time in the year, each of the districts makes

good provision for forage crops for the work stock, and this is accomplished without interference with the main business of growing truck crops for sale.

With respect to their total area, the three fine sandy loam types lead in the production of the potato crop, the Sassafras sandy loam is next in importance, and the Keyport sandy loam and Norfolk coarse sandy loam are least important among the more extensive soil types.

It should be held in mind that both the Keyport and Suffolk fine sandy loams have been provided with excellent systems of tile underdrains within the section covered by the Churchland area survey, and that these figures represent the two types at their best with regard to potato growing. This fact is of considerable importance, since there remain in the region very considerable areas of each of these soils which are thus proved to be of a high degree of usefulness for potato growing whenever proper drainage is installed.

Table XV summarizes the potato acreage of the three areas according to soil type.

TABLE XV.—*Acreage of potatoes, according to soil type, in the Churchland, Diamond Springs, and Onley areas, combined.*

Soil type.	Area planted.	Proportion of type occupied.	Proportion of cropped area of the type.	Proportion of total crop.
	Acres.	*Per cent.*	*Per cent.*	*Per cent.*
Norfolk fine sandy loam	299.0	61.2	66 8	26.2
Sassafras sandy loam	236.0	30.4	44.7	20.8
Keyport sandy loam	128.0	26.8	32.2	11.3
Keyport fine sandy loam	123.4	58.6	61.4	10.9
Suffolk fine sandy loam	71.8	49.2	66.8	6.3
Norfolk coarse sandy loam	63.2	21.7	36.0	5.6

Table XVI summarizes the data for strawberries.

TABLE XVI.—*Acreage of strawberries, according to soil type, in the Churchland, Diamond Springs, and Onley areas, combined.*

Soil type.	Area planted.	Proportion of type occupied.	Proportion of cropped area of the type.	Proportion of total crop.
	Acres.	*Per cent.*	*Per cent.*	*Per cent.*
Sassafras coarse sandy loam	100.3	36.1	55.2	25.4
Norfolk coarse sandy loam	80.0	27.6	36.0	20.3
Norfolk loam	41.1	8.3	33.0	10.4
Norfolk fine sandy loam	31.2	6.4	7.0	7.9

The two coarse sandy loams are clearly the preferred strawberry soils, while the crop is scattering on the other types encountered. It should be stated that strawberries are also grown extensively on

soils of the Portsmouth series somewhat to the south of the areas where the surveys were made, and that the crop is well suited to production on both the Portsmouth sandy loam and fine sandy loam, where these have been properly drained. Soils of the Keyport and Elkton series are also used for the production of the crop.

In Table XVII the data for the three areas, relating to sweet potatoes, are combined to show soil-type occupancy.

TABLE XVII.—*Acreage of sweet potatoes, according to soil type, in the Churchland, Diamond Springs, and Onley areas, combined.*

Soil type.	Area planted.	Proportion of type occupied.	Proportion of cropped area of the type.	Proportion of total crop.
	Acres.	*Per cent.*	*Per cent.*	*Per cent.*
Sassafras sandy loam	173.4	22.4	32.8	54.9
Keyport sandy loam	70.0	14.7	23.5	22.1
Elkton sandy loam	38.2	8.2	26.1	12.7

The Sassafras sandy loam is clearly the preferred sweet-potato soil in this region. There is no doubt that the crop could also be grown successfully upon the coarse sandy loams, and would be were it not that these soils are desired for strawberry growing and the production of the winter crop of cabbage. Either one of these crops interferes with the growing of sweet potatoes and the truckers evidently prefer them to the moderate profits which may be obtained from sweet potato growing.

Cabbage is grown rather indiscriminately upon the Norfolk coarse sandy loam, Keyport fine sandy loam, and Norfolk fine sandy loam, principally. The chief requirements seem to be a position sheltered against winter winds, fairly good drainage, and rather strong forcing by the use of fertilizers applied during the milder days of winter.

The relationships of spinach and kale to the different soils have been shown in the discussion of the Churchland and Diamond Springs areas. No distinctively winter truck crops are grown within the limits of the Onley survey.

GENERAL SUMMARY.

There are two important trucking districts in eastern Virginia, the Norfolk and the Eastern Shore districts.

The Norfolk district lies south of the James River and Chesapeake Bay. In this district from 50,000 to 60,000 acres of truck crops are grown annually.

The Eastern Shore district comprises the greater part of Accomac and Northampton Counties, and 85,000 to 95,000 acres of truck crops are annually grown in it.

Both areas receive an adequate amount of precipitation ranging from 40 to 50 inches a year. It is usually well distributed. The Norfolk district has a growing season between killing frosts of 230 days. The southern portion of the Eastern Shore district has a growing season of 210 to 220 days, while the remainder of the district has a growing season of 185 to 210 days. Close proximity to large bodies of tidewater results in favorable climatic conditions in both districts. The Norfolk district constitutes the most northern of the year-round trucking districts.

Shipments of truck crops are made from each district to all of the larger northern and northeastern cities and even to Canada. Both rail and water transportation are employed. Shipments are largely made through truckers' associations.

The trucking business is chiefly carried on by native white farmers with negro laborers.

The entire region is marked by low relief, rising not more than 50 feet above tide level. There are no great irregularities of surface, very little erosion, and the land is drained chiefly through deep-cut estuaries and small upland streams. Broad undrained areas exist upon the uplands between the more pronounced drainage ways.

The soils of the region are derived from the unconsolidated deposits of the Atlantic Coastal Plain and range in texture from sands and coarse sandy loams to rather heavy loams. Sandy loams and fine sandy loams predominate, constituting the chief areas used for intensive agricultural occupation. The different soil series follow natural drainage conditions rather closely in their distribution. Soils of the Sassafras and Norfolk series are well drained and occupy low ridges or areas near the main drainage ways. Soils of the Keyport series are fairly well drained and are found on level or gently sloping uplands. Soils of the Elkton and Suffolk series occupy broad flat areas on the uplands more remote from established drainage and are found also in basin-shaped areas around stream heads. Soils of the Portsmouth series, marked by surface accumulations of dark-colored organic matter, occur in upland swamps and along wet stream margins. Some areas have been artificially drained. Tidal marsh and dunes and are not occupied agriculturally.

Soil and crop maps were made of three areas. The Churchland area, representing conditions between the Elizabeth and Nansemond Rivers; the Diamond Springs area, representing those between Elizabeth River and the Atlantic Ocean; and the Onley area, representing conditions in the central portion of the Eastern Shore of Virginia. Both spring and fall crop maps were made to show the year-round crop occupation of the different soils.

From these maps it appears that—

Well-drained sandy loam and fine sandy loam soils are strongly preferred for the growing of truck crops.

In the Norfolk district the Norfolk fine sandy loam is the most extensive and most important trucking soil. The Sassafras fine sandy loam is much less extensive, but is highly esteemed for truck crop production. The Sassafras and Norfolk coarse sandy loams are of small extent, but are extensively occupied for the growing of both summer and winter truck crops. Loam and gravelly loam soils and even fine sandy loam soils of the Keyport and Suffolk series require artificial drainage to become fitted for truck crop production, but are then suited to such crops as potatoes, cabbage, and kale.

Potatoes constitute the leading crop in acreage in the Norfolk district, cabbage and strawberries are very important crops, and spinach and kale constitute the chief winter crops. A large number of less important crops are grown, including beans, peas, cucumbers, cantaloupes, beets, turnips, radishes, and other minor crops.

On the Eastern Shore of Virginia the Sassafras sandy loam is the most extensive and important truck soil. The Keyport sandy loam and Sassafras fine sandy loam are also extensively used.

Potatoes constitute the most extensively grown crop, sweet potatoes are second in importance, and strawberries, cabbage, and onions are the other important truck crops.

The Norfolk district is marked by year-round trucking; the Eastern Shore district is characterized by the growing of a potato crop in early summer, the land being occupied by forage crops after the potatoes are harvested.

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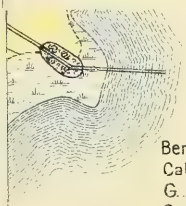
UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 1006



Interplanting

Corn
Cowpeas

ABBREVIATIONS

Berry.....Strawberry
Cab.....Cabbage
G.....Garden
Orch.....Orchard
Sweets.....Sweet Potato
Spin.....Spinach
T.P.....Turnip
House and Yard.....
Church.....
Swamp.....
Canal.....
Forest boundary.....

Surveyed by J. A
U.S. Departmen

Bulletin 1005, U. S. Department of Agriculture

U.S. DEPT. OF AGRICULTURE
BUREAU OF SOILS
MILTON WHITNEY, CHIEF
CURTIS F. MARBUT, IN CHARGE SOIL SURVEY

SOIL AND CROP MAP

JUNE 1916

VIRGINIA
CHURCHLAND SHEET

Surveyed by J. A. Bonsteel of the U.S. Department of Agriculture.

Scale in feet

1000 500 0 1000 2000 3000

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BULLETIN No. 1006

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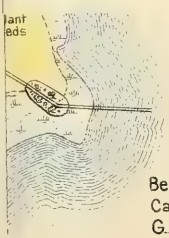

SYMBOLS AND ABBREVIATIONS

Interplanting

Corn
Cowpeas

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AUGUST 1916

VIRGINIA
CHURCHLAND SHEET

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BUREAU OF SOILS
MILTON WHITNEY, CHIEF
CURTIS F. MARBUT, IN CHARGE SOIL SURVEY

SOIL AND CROP MAP

NOVEMBER 1915

VIRGINIA
DIAMOND SPRINGS SHEET

LEGEND

Sassafras coarse sandy loam	62
Sassafras fine sandy loam	43
Sassafras loam	46
Norfolk coarse sandy loam	4
Norfolk gravelly sandy loam	30
Norfolk gravelly loam	35
Norfolk loam	44
Norfolk silt loam	32
Suffolk loam	13
Suffolk gravelly loam	10

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Scale in feet

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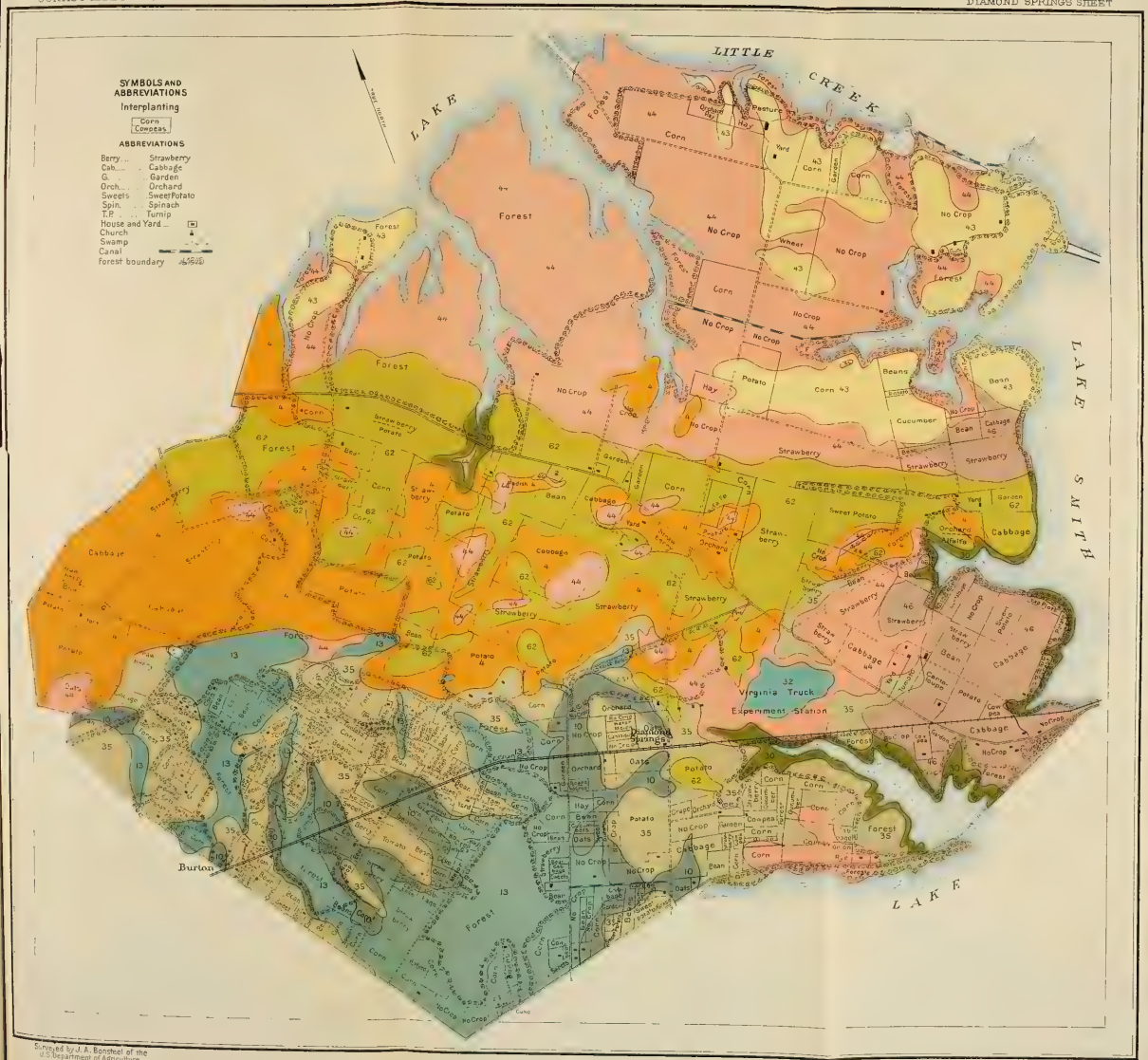
SOIL AND CROP MAP
JUNE 1916

VIRGINIA
DIAMOND SPRINGS SHEET



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Scale in feet
1000 0 1000 2000 3000

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BUREAU OF SOILS
MILTON WHITNEY, CHIEF
CURTIS F. MARBUT, IN CHARGE SOIL SURVEY

SOIL AND CROP MAP

JULY 1916

VIRGINIA
ONLEY SHEET

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Scale in feet

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SOIL AND CROP MAP

SEPTEMBER 1916

VIRGINIA
ONLEY SHEET

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 1006

Contribution from the Bureau of Markets and Crop Estimates.

H. C. TAYLOR, Chief

Washington, D. C. ▼ November 12, 1921

ACCOUNTING RECORDS FOR SAMPLING APPLES BY WEIGHT.

By J. H. Conn, *Assistant in Market Business Practice*, and A. V. Swarthout, *Investigator in Market Business Practice.*

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The forms and their use	2	Table of reciprocals	8
Method of operation	4	Forms	10
Condensed operating schedule	7	Progress chart	12

INTRODUCTION.

Throughout the Pacific Northwest community packing of apples is rapidly growing in popularity. This service is performed in thoroughly modern packing houses equipped with up-to-date machinery and labor-saving devices, and the packing room is separate from that used for storage or other purposes.

It is the usual custom to pack the fruit of each grower separately and to record the results of the "pack-out" to the credit of the growers' accounts. It is imperative, therefore, that the identity of the ownership of the fruit be maintained on the warehouse floor until a complete tally has been made of the various grades and sizes, and the proper credit has been entered on the growers' accounts. Such a plan necessitates a very carefully devised system of warehouse-floor checking as a safeguard against confusing the ownership of the fruit prior to its being packed. This is particularly true during a season in which the tonnage is extremely heavy and the loose fruit storage space is limited. During the rush of business in the fall of the year, shippers are often compelled to pile fruit to the ceiling in their efforts to provide storage space for all deliveries and still retain the identity of each growers' fruit until it is properly recorded.

Within recent years several fruit-shipping organizations have adopted a system of sampling apples by weight. This system is

unique in the scheme employed to establish a record of the various grades and sizes of apples packed for each grower. The aim of this method is to accelerate the movement of the fruit through the packing rooms and to avoid the expense of repiling and checking that so frequently arises in attempting to retain the identity of each growers' lot of loose fruit on the packing-house floor. A sample is selected from each lot of fruit received. This sample is graded and sized, and a record made of the weight of each grade and size in the sample. The percentage relation of the total weight of the sample to the total weight of the lot is then applied to ascertain the weight of the various grades and sizes that make up the load, and the grower is given credit for the total weight, classified as to grades and sizes.

THE FORMS AND THEIR USE.

Accounting forms have been devised for use in community packing houses operating in the usual way. A complete description of those forms may be found in United States Department of Agriculture Bulletin 590, A System of Accounting for Fruit-Shipping Organizations. Ample provision has been made in them for the adequate handling of the business performed by most of the fruit-shipping institutions. However, with the introduction of the sample test plan as a means of determining the various grades and sizes packed for each grower's account, a condition has been created which is entirely different from that existing in other organizations. For this reason special forms are required.

All forms described in Bulletin 590 can be used by packing houses that sample fruit by the weight method, with the exception of the Loose Fruit Receipt Form No. 9, Packed Fruit Receipt Form No. 11, Register of Receipts Form No. 12, Reconcilement of Fruit Deliveries Form No. 13, and Account Sales Form No. 21. To take the place of these, five new forms are presented in this bulletin.

The new forms have been devised with the view of relieving the sample test clerk of all unnecessary clerical work so that the weighing of each sample may be carried on without undue interruptions or delays.

THE LOOSE-FRUIT RECEIPT.

The loose fruit receipt (Form No. 1) is made out in triplicate; the original copy is given to the grower, the duplicate tissue copy is sent to the office, and the triplicate cardboard copy follows the sample through the test room. A small tin holder is attached to one of the boxes of the sample and in this the triplicate of the receipt is inserted. This card serves as a means of identification of the sample until it has been graded.

THE SAMPLED-FRUIT RECEIPT.

The sampled-fruit receipt (Form No. 2) is made in duplicate; the original is given to the grower and the duplicate is retained in the office files. This form shows the weight of each sample after classification into grade and size groups, and the total weight of the load similarly classified.

Considerable care and attention are necessary in the preparation of the sampled-fruit receipt, particularly in recording the test weights. This record is the original entry of the number of pounds of fruit of the various grade and size groups credited to the grower's account, and all future computations are based on these figures.

THE REGISTER OF SAMPLED-FRUIT RECEIPTS.

The register of sampled-fruit receipts (Form No. 3) is made in duplicate. The original copy serves as an office record, and the duplicate (further described as the reconcilement of fruit deliveries, Form No. 4) serves as a statement for the grower.

To facilitate posting, the register of receipts is placed on the upper part of the sheet occupied by the account sales form. This is done so that the clerical work entailed in determining the fruit contributed to the various pools may be reduced to a minimum by merely carrying down the totals.

Accounts are opened in the register of sampled-fruit receipts under the names of the various growers. One sheet is provided for each variety brought in by each grower. The receipts are posted daily, thus making available at all times a full and complete record of the quantity, grades, and sizes received for each grower's account.

THE RECONCILEMENT OF FRUIT DELIVERIES.

In order to avoid clerical work entailed in rectifying errors which may be found after pools have been closed, the reconcilement of fruit deliveries (Form No. 4) has been prepared. This form is the duplicate copy of the register of sampled-fruit receipts, and is arranged as a statement of the total amount of fruit packed for each grower, classified according to grades and sizes.

Growers are requested to compare carefully the figures on the reconcilement statement with the total quantity of fruit appearing on the sampled-fruit receipts held by them, and to report any discrepancies promptly.

Before issuing, these statements should be carefully checked with the sampled-fruit receipts so as to discover any errors in posting.

THE ACCOUNT SALES.

The account sales (Forms No. 5 and 5a) is drawn up in the form of a duplicating ledger statement; the original copy is retained in the

office and the duplicate copy forwarded to the growers for their information. The original copy of this form occupies the lower part of the sheet provided for the register of sampled-fruit receipts, the duplicate copy occupying the lower part of the sheet provided for the reconcilement of fruit deliveries. Perforated lines permit them to be separated easily.

As soon as all discrepancies have been reported and the proper corrections made on the reconcilements, the total weights are reduced to boxes and transferred to the account sales. The information shown on the account sales includes the classification of fruit by grades and sizes, net average prices per box (after all selling and handling charges have been deducted), and net returns for each variety of fruit.

METHOD OF OPERATION.

RECEIVING LOOSE FRUIT.

Fruit is delivered to the community packing house in open boxes without being sorted into grades or sizes. As each lot is unloaded, a loose fruit receipt (Form No. 1) is made out in triplicate. The original is given to the grower as evidence of the delivery of the fruit, the duplicate (tissue) copy is sent to the office for filing, and the triplicate (cardboard) copy is attached to one of the boxes of each sample by means of a small tin holder and serves as a means of identifying the sample in the test room. The office copy of each loose-fruit receipt is held in a temporary file awaiting the receipt of the triplicate cardboard copy used to identify the samples.

It is advisable to check over the numerical order of the receipts turned into the office each day by the sample clerk to be sure that none are missing. This is a very important practice and should be enforced rigidly as protection for the growers' account. To facilitate posting, receipts are then arranged alphabetically, according to growers' names. By referring to the temporary file, it is possible to determine at any time the quantity of fruit remaining in the sample room to be tested and also to determine the length of time samples are held before being tested.

The number of boxes selected as a sample from each load varies with the size of the load. It is usual to set aside 1 box in every 20 (about 5 per cent) as a fair test of each load of fruit delivered. No fixed quantity is required, as it is generally felt that, regardless of the size of the sample, an accurate test will be obtained. After attaching the triplicate of the loose fruit receipt to one box of the sample, it is trucked into the test room, and the remainder of the load is stacked with the unpacked fruit of the same variety.

SORTING AND RECORDING.

All results obtained by the test clerk in determining the net weights of each grade and size group contained in any one sample are recorded on the duplicate copy of the sampled-fruit receipt. From the triplicate of the loose-fruit receipt the net weight of the fruit, including the boxes, is transcribed on the sampled-fruit receipt (Form No. 2) in the space provided under the caption, Loose-fruit weights. The weights of the various grades and sizes contained in the sample are recorded on the sampled-fruit receipt under the caption, Test weights. These figures are then checked daily in the office as a safeguard against errors. To accelerate the sampling work, the test clerk records only the weights of each lot without working out any percentage figures. Several samples belonging to a grower are often combined and one test made of the combined lots, especially when the tests are small. At the close of each day all sampled-fruit receipts are sent to the office to be entered on the growers' accounts.

The work of ascertaining the net weights of each grade and size group must be very accurate and painstaking. To facilitate matters, the scales used in the sampling operations are fitted with beams giving the readings in pounds and decimal parts instead of ounces. The grading of samples is usually performed on a small model of the machines used in the general packing room.

As each day's sampled-fruit receipts are received in the office, the numbers are checked consecutively and a comparison made with the loose-fruit receipts held in the temporary file. The checking of the test clerks' computations on the duplicate copy of the sampled-fruit receipt is worthy of special emphasis and should be carefully performed. The percentage of test and the total weights of each grade and size group depend upon the accuracy of the test clerk's computations.

The following items on the duplicate sampled-fruit receipt should be carefully checked against like items appearing on the loose fruit receipt:

1. Net weight of fruit, boxes included.
2. Number of boxes containing fruit.

The following computations made by the test clerk and entered on the duplicate sampled-fruit receipt should be carefully checked:

1. Net weight of boxes delivered containing fruit (number of boxes times the arbitrary net weight of each box).
2. Net weight of fruit delivered (net weight of fruit, including boxes minus weight of boxes).
3. Net weight of each tested lot appearing under the caption Test weights (gross weight of fruit, including the bin minus the weight of the bin).
4. Total test weights.

COMPUTING THE GRADE AND SIZE GROUP WEIGHTS.

It is the duty of the office clerk in charge of receipts to ascertain what percentage the fruit in the sample is of the total fruit on the load and to compute the weights of the various grades and sizes. This percentage is found by dividing the total net weight of the sample by the net weight of the fruit on the load. For example:

Assume that 163.2 pounds is the net weight of the whole sample and that 4,000 pounds is the net weight of the load of fruit. To determine the percentage of test: 163.2 divided by 4,000 equals 4.08 per cent.

Having determined the percentage of test, it is a comparatively simple matter to compute the total weight of each grade and size in the lot from the results of the test, as reported by the test clerk under "Test weights" on the sampled-fruit receipt. This can be done either by dividing the test weights by the percentage of test, or by multiplying the test weight by the reciprocal of the percentage of test, as shown in the table on page 9.

Now, the percentage of test is 4.08 per cent. Suppose that the Extra Fancy (36–125) test weight is 50.2 pounds; Fancy (36–125) test weight, 75.6 pounds; "C" grade (36-163) test weight, 37.4 pounds. To compute the weights of the various grades in this size group by the percentage division method:

	Test weights.		Total weights.
Extra Fancy (36–125)	50. 2 pounds divided by 0.0408 equals		1, 230. 40 pounds.
Fancy (36–125)	75. 6 pounds divided by 0.0408 equals		1, 852. 94 pounds.
"C" (36–163)	37. 4 pounds divided by 0.0408 equals		916. 66 pounds.
Total	163. 2 pounds		4, 000. 0 pounds.

(In this method the percentage is expressed as hundredths, i. e., 0.04 is used instead of 4 per cent, hence there can never be less than two decimal places in the divisor.)

To determine the weights by the reciprocal-multiplier method: The reciprocal of 4.08 per cent test is 24.51 (see Table of reciprocals, p. 9).

	Test weights.		Total weights.
Extra Fancy (36–125)	50. 2 pounds times 24. 51 equals		1, 230. 40 pounds.
Fancy (36–125)	75. 6 pounds times 24. 51 equals		1, 852. 94 pounds.
"C" (36–163)	37. 4 pounds times 24. 51 equals		916. 66 pounds.
Total	163. 2 pounds		4, 000. 00 pounds.

To facilitate the above computations the reciprocals are carried out only two decimal places and the last digit of the total weight is corrected as a means of obtaining a balance.

REGISTERING THE SAMPLED-FRUIT RECEIPTS.

The weights of the various grade and size groups appearing on the sampled-fruit receipts are entered daily on the register of sampled-

fruit receipts (Form No. 3). (The receipts should first be arranged in numerical order to be sure that none are missing, and then rearranged in alphabetical order to facilitate posting.) These entries should be checked back daily as a safeguard against errors in posting. If this practice is followed, the reconcilements can be forwarded to growers immediately at the close of the packing season, without further checking. At the conclusion of the packing season the weights appearing in the various grade and size groups are totaled and reduced to boxes. After this is done all records are in terms of boxes and the reconcilement of fruit delivered is ready to be sent to the growers. This should not be done, however, until the number of boxes of the various grades and sizes has been entered on the account sales.

REPORTS TO GROWERS.

An account sales (Forms No. 5 and 5A) should be made out for each variety contributed by a grower. Posting the number of boxes to this form must be done before closing the pools. The form furnishes a complete record of the quality and quantity of fruit contributed by the various growers to a given pool. It is made in duplicate, the original copy being filed in the office and the duplicate serving as a statement for the grower.

To facilitate posting at the time of closing the pools, account sales are arranged in alphabetical order according to varieties, and then numbered. For reference purposes a recapitulation of the total number of boxes in the pool, classified according to grades and sizes, should be prepared and filed on top of the growers' distribution sheets. This permits the contents of the pool to be seen at a glance.

The average prices shown on the account sales are computed after deducting all selling and handling charges from the gross sales of the fruit. Such items as packing, building and equipment deductions, or part payments on capital stock notes are charged to the grower's ledger account. Account sales should in all cases be forwarded to growers immediately following the closing of each pool.

CONDENSED OPERATING SCHEDULE.

A condensed analysis of the application of the special forms devised for sampling apples by weight, together with a brief outline of the practices involved arranged in the order of their intended use, follows:

Loose fruit receiving room:

1. Loose fruit unloaded.
2. Gross, tare, and net weight of the fruit, including the weight of the boxes entered on loose fruit receipt.
3. Sample selected from the load.
4. Sample sent to test room, remainder of load trucked to packing room.
5. Duplicate loose fruit receipts sent into office daily, original given to the grower, triplicate attached to test box.

Sample test room:

1. Sample sorted and weighed, classified as to grades and sizes.
2. Test weight computations entered on duplicate sampled-fruit receipt.
3. Test weights entered on sampled-fruit receipt.
4. Loose fruit receipt number entered on sampled-fruit receipt.
5. Sampled-fruit receipts and triplicate loose fruit receipts sent into office daily.

Office:

1. Sampled-fruit receipts and loose fruit receipts received daily.
2. Numerical order of sampled-fruit receipts and loose fruit receipts checked, then rearranged in alphabetical order. Missing receipts noted.
3. Loose fruit receipts covering a given test withdrawn from temporary file and placed in permanent file.
4. Test clerk's computations checked on duplicate sampled-fruit receipt.
5. Percentage of test determined and noted.
6. Reciprocal of percentage of test determined and noted.
7. Extensions of the total weights made on the sampled-fruit receipt, classified as to grades and sizes.
8. Original copy of sampled-fruit receipts sent to growers, duplicate copy entered on register of sampled-fruit receipts, then placed in permanent file.
9. Register of sampled-fruit receipts arranged in alphabetical order.
10. Sampled-fruit receipts entered daily on register of sampled-fruit receipts.
11. Footings totaled on register of sampled-fruit receipts at the close of the packing season. Weights reduced to boxes.
12. Reconcilement of fruit deliveries sent to growers at the close of the packing season.
13. Account sales arranged according to varieties and numbered.
14. Footings of the register of receipts brought down on the account sales at the close of the packing season.
15. Upon closing pools entries are made on tne account sales, setting forth the net average prices of the fruit, classified as to grades and sizes, extensions made in the amount column, duplicate copies sent to the growers, and original copies held in the permanent file.

STATEMENTS AND LEDGER ACCOUNTS.

The various financial statements used in exhibiting the condition of business at the close of the fiscal year, together with a full description of the classified ledger accounts used in recording all business transactions, are set forth in United States Department of Agriculture Bulletin 590, A Classification of Ledger Accounts for Fruit Shipping Organizations.

TABLE OF RECIPROCALS.

The reciprocals of the percentage of test, from 2 to 5 per cent (extended to two decimal places), used as multipliers in determining the total weight of the load classified as to grades and sizes, are as follows:

Table of reciprocals.

Per cent test.	Reciprocals.	Per cent test.	Reciprocals.	Per cent test.	Reciprocals.	Per cent test.	Reciprocals.
2.00	50.00	2.76	36.23	3.52	28.41	4.28	23.36
2.01	49.75	2.77	36.10	3.53	28.33	4.29	23.31
2.02	49.50	2.78	35.97	3.54	28.25	4.30	23.26
2.03	49.26	2.79	35.84	3.55	28.17	4.31	23.20
2.04	49.02	2.80	35.71	3.56	28.09	4.32	23.15
2.05	48.78	2.81	35.59	3.57	28.01	4.33	23.10
2.06	48.54	2.82	35.46	3.58	27.93	4.34	23.04
2.07	48.31	2.83	35.33	3.59	27.85	4.35	23.00
2.08	48.08	2.84	35.21	3.60	27.78	4.36	22.94
2.09	47.85	2.85	35.09	3.61	27.70	4.37	22.89
2.10	47.62	2.86	34.97	3.62	27.62	4.38	22.83
2.11	47.40	2.87	34.84	3.63	27.55	4.39	22.78
2.12	47.17	2.88	34.72	3.64	27.47	4.40	22.73
2.13	46.95	2.89	34.60	3.65	27.40	4.41	22.68
2.14	46.73	2.90	34.48	3.66	27.32	4.42	22.62
2.15	46.51	2.91	34.36	3.67	27.25	4.43	22.57
2.16	46.30	2.92	34.25	3.68	27.18	4.44	22.52
2.17	46.08	2.93	34.13	3.69	27.10	4.45	22.47
2.18	45.87	2.94	34.01	3.70	27.03	4.46	22.42
2.19	45.66	2.95	33.90	3.71	26.95	4.47	22.37
2.20	45.45	2.96	33.78	3.72	26.88	4.48	22.32
2.21	45.24	2.97	33.67	3.73	26.81	4.49	22.27
2.22	45.04	2.98	33.56	3.74	26.74	4.50	22.22
2.23	44.84	2.99	33.44	3.75	26.66	4.51	22.17
2.24	44.64	3.00	33.33	3.76	26.60	4.52	22.12
2.25	44.44	3.01	33.23	3.77	26.53	4.53	22.08
2.26	44.25	3.02	33.11	3.78	26.45	4.54	22.03
2.27	44.05	3.03	33.00	3.79	26.38	4.55	21.98
2.28	43.86	3.04	32.90	3.80	26.32	4.56	21.93
2.29	43.67	3.05	32.79	3.81	26.25	4.57	21.88
2.30	43.48	3.06	32.68	3.82	26.18	4.58	21.84
2.31	43.29	3.07	32.57	3.83	26.11	4.59	21.79
2.32	43.10	3.08	32.47	3.84	26.04	4.60	21.74
2.33	42.92	3.09	32.36	3.85	25.97	4.61	21.69
2.34	42.74	3.10	32.26	3.86	25.91	4.62	21.65
2.35	42.55	3.11	32.15	3.87	25.84	4.63	21.60
2.36	42.37	3.12	32.05	3.88	25.77	4.64	21.55
2 37	42.19	3.13	31.95	3.89	25.71	4.65	21.50
2.38	42.02	3.14	31.85	3.90	25.64	4.66	21.46
2.39	41.84	3.15	31.74	3.91	25.58	4.67	21.41
2.40	41.67	3.16	31.64	3.92	25.51	4.68	21.37
2.41	41.49	3.17	31.54	3.93	25.45	4.69	21.32
2.42	41.32	3.18	31.44	3.94	25.38	4.70	21.28
2.43	41.15	3.19	31.35	3.95	25.32	4.71	21.23
2.44	40.98	3.20	31.25	3.96	25.25	4.72	21.19
2 45	40.82	3.21	31.15	3.97	25.19	4.73	21.14
2.46	40.65	3.22	31.05	3.98	25.13	4.74	21.10
2.47	40.49	3.23	30.96	3.99	25.06	4.75	21.05
2.48	40.32	3.24	30.86	4.00	25.00	4.76	21.01
2.49	40.16	3.25	30.77	4.01	24.93	4.77	20.97
2.50	40.00	3.26	30.67	4.02	24.87	4.78	20.92
2.51	39.84	3.27	30.58	4.03	24.81	4.79	20.88
2.52	39.68	3.28	30.49	4.04	24.75	4.80	20.83
2.53	39.53	3.29	30.40	4.05	24.69	4.81	20.79
2.54	39.37	3.30	30.30	4.06	24.63	4.82	20.75
2.55	39.22	3.31	30.21	4.07	24.57	4.83	20.71
2.56	39.06	3.32	30.12	4.08	24.51	4.84	20.66
2.57	38.91	3.33	30.03	4.09	24.45	4.85	20.62
2.58	38.76	3.34	29.94	4.10	24.40	4.86	20.58
2.59	38.61	3.35	29.85	4.11	24.33	4.87	20.53
2.60	38.45	3.36	29.76	4.12	24.27	4.88	20.50
2.61	38.31	3.37	29.67	4.13	24.22	4.89	20.45
2.62	38.17	3.38	29.58	4.14	24.16	4.90	20.41
2.63	38.02	3.39	29.50	4.15	24.10	4.91	20.37
2.64	37.88	3.40	29.41	4.16	24.04	4.92	20.32
2.65	37.74	3.41	29.33	4.17	23.98	4.93	20.28
2.66	37.60	3.42	29.24	4.18	23.93	4.94	20.24
2.67	37.45	3.43	29.15	4.19	23.87	4.95	20.20
2.68	37.31	3.44	29.06	4.20	23.81	4.96	20.16
2.69	37.17	3.45	28.98	4.21	23.76	4.97	20.12
2.70	37.04	3.46	28.90	4.22	23.70	4.98	20.08
2.71	36.90	3.47	28.82	4.23	23.64	4.99	20.04
2.72	36.76	3.48	28.74	4.24	23.59	5.00	20.00
2.73	36.63	3.49	28.66	4.25	23.53		
2.74	36.50	3.50	28.57	4.26	23.47		
2.75	36.36	3.51	28.49	4.27	23.42		

B. of M. Form 1

LOOSE FRUIT RECEIPT

No.....

Name.....

Received on Account of ..... 192....

The following is received in open boxes, for packing without guaranty from the undersigned as to the variety, grade, or weight of the fruit.

Number of Boxes	VARIETY	Gross Weight	
		TARE	
		Net Weight Boxes Incl.	

Number Boxes in Test.....

Truck Ticket No..... Hauled by.....

Remarks:.....

Name.....

Entered by..... Per.....

B of M Form 2 SAMPLED-FRUIT RECEIPT No.....

NAME.....

RECEIVED ON ACCOUNT OF..... VARIETY.....

LOOSE FRUIT WEIGHTS			TEST WEIGHTS				TOTAL WEIGHTS	
NET WEIGHT FRUIT, BOXES INCLUDED			EXTRA FANCY	36-125 a36-88				
NUMBER BOXES CONTAINING FRUIT [ ]				138-163 a96-125				
NET WEIGHT BOXES				175&-S a138&S				
NET WEIGHT FRUIT								
IMPORTANT			FANCY	36-125 a36 88				
				138-163 a96-125				
THIS RECEIPT IS NOT NEGOTIABLE				175&-S a138&S				
PLEASE EXAMINE IT VERY CAREFULLY. IN CASE OF ERROR HAVE SAME RECTIFIED AT ONCE.			C	36-163				
				175&S				
			CULLS					
			TOTAL					
			PER CENT OF TEST.....					

a. THE ABOVE DIVISION OF SIZES PERTAINS TO DELICIOUS, BANANA, AND ROME BEAUTY.

NUMBER OF TEST BOXES..... NAME.....

LOOSE FRUIT RECEIPT NO..... ENTERED BY.... PER.....

Size of form 6½ by 6½ inches, exclusive of binding margin. This form is the original copy of Form 2. In pads of 50, alternating original and duplicate (see duplicate Form 2) stapled and perforated.

B of M Form 2 SAMPLED-FRUIT RECEIPT No.

RECEIVED ON ACCOUNT OF..... VARIETY.....

LOOSE FRUIT WEIGHTS			TEST WEIGHTS				TOTAL WEIGHT	
NET WEIGHT FRUIT, BOXES INCLUDED			EXTRA FANCY	36-125 a36 88				
NUMBER BOXES CONTAINING FRUIT [ ]				138-163 a96-125				
NET WEIGHT BOXES				175&-S a138&S				
NET WEIGHT FRUIT								
TEST CLERK'S COMPUTATIONS			FANCY	36-125 36-88				
EXTRA FANCY		BOXES		138-163 a96-125				
		"C"		175&-S a138&S				
			C	36-163				
FANCY				175&S				
		CULLS						
			CULLS					
DUPLICATE			TOTAL					
			PER CENT OF TEST.....					

a. THE ABOVE DIVISION OF SIZES PERTAINS TO DELCIOUS, BANANA, AND ROME BEAUTY.

NUMBER OF TEST BOXES..... NAME.....

LOOSE FRUIT RECEIPT NO..... ENTERED..... PER.....

Lettering and ruling same as original except as above noted.

ORIGINAL COPY

B. of M. Form 3
REGISTER OF
SAMPLED-FRUIT RECEIPTS

VARIETY

Mr. 192

DATE	RECEIPT NUMBER	EXTRA FANCY			FANCY			"C"		CULLS	PER CENT OF TEST	TOTAL
		a 96-125 a 36-88	138-163 a 96-125	175-6 a 138-5	36-125 a 36-88	138-163 a 96-125	175-6 a 138-5	96-163	175-6			
TOTAL NO. POUNDS												
TOTAL NO. BOXES												

B. of M. Form 5

ACCOUNT SALES FILE NO

												NET AV'G PRICE	AMOUNT

a—THE ABOVE DIVISION OF SIZES PERTAINS TO DELICIOUS, BANANA, ROME BEAUTY.

62646°—21. (To follow p. 11.) No. 1. Size of form 11½ by 11⅞ inches, punched 8¼-inch centers, 11/16-inch posts.

DUPLICATE COPY

B. of M. Form 4
RECONCILEMENT OF
FRUIT DELIVERIES

NAME.....

VARIETY.....

Mr.

192

BELOW IS A STATEMENT OF THE NUMBER OF POUNDS OF FRUIT OF THE ABOVE VARIETY. DELIVERED BY YOU TO DATE AS SHOWN BY OUR RECORDS. KINDLY COMPARE THESE FIGURES WITH YOUR RECORDS. REPORT ANY DISCREPANCY IMMEDIATELY.

DATE	RECEIPT NUMBER	EXTRA FANCY						FANCY						"C"						CULLS		PER CENT OF TEST		
		36-125 a 36-88		138-163 a 96 125		175-S a 138-S		36-125 a 36-88		138-163 a 96-125		175-S a 138-S		36-163		175-S								
TOTAL NO. POUNDS																								
TOTAL NO. BOXES																								

B of M. S.A

NAME

ACCOUNT SALES Mr. _____ FILE NO. ____ VARIETY _____

		EXTRA FANCY						FANCY						"C"						CULLS		NET AVG PRICE		AMOUNT	
		36-125 a 36-88		138-163 a 96 125		175-S a 138-S		36-125 a 36-88		138 163 a 96 125		175-S a 138-S		36-163		175-S									

a-THE ABOVE DIVISION OF SIZES PERTAINS TO DELICIOUS, BANANA, AND ROME BEAUTY

WE ARE TODAY CREDITING YOUR ACCOUNT WITH THE AMOUNT OF THIS ACCOUNT SALES

62646°—21. (To follow p. 11.) No. 2. Size of form 11½ by 11⅞ inches, punched 8½-inch centers, 1/16-inch posts.

PROGRESS CHART

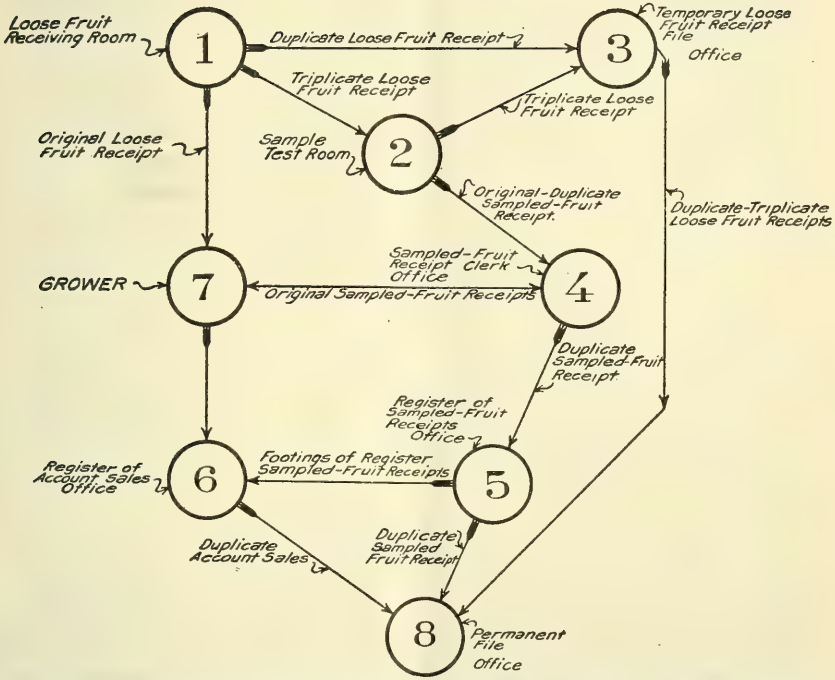

Chart indicating the progress of the special forms used in recording the weights of the fruit from the time it is received for packing until fully accounted for. The numbers in the circles indicate the channels through which the forms pass:

No. 1. Loose-fruit receiving room.
No. 2. Sample test room.
No. 3. Temporary loose-fruit receipt file—office.
No. 4. Sampled-fruit receipt clerk—office.
No. 5. Register of sampled-fruit receipts—office.
No. 6. Register of account sales—office.
No. 7. Grower.
No. 8. Permanent files—office.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 1007

Contribution from the Forest Service
WILLIAM B. GREELEY, Forester.

Washington, D. C. PROFESSIONAL PAPER June 5, 1922

UTILIZATION OF BASSWOOD

By Warren D. Brush, *Scientific Assistant.*

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Supply	5	Summary	56
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INTRODUCTION.

Basswood is one of the important commercial timbers of the United States. Nineteen other woods are manufactured into lumber in larger quantities, and factories using lumber for the manufacture of various wooden products consume larger quantities of about 12 other woods, including yellow poplar and white pine, which are often used for the same general class of products as basswood and are frequently substituted for it.

Basswood is valued mainly for its white color, light weight, and good working qualities. It is well adapted for certain special uses for which other woods do not serve as well, and, because of the comparatively small supply now available, it is greatly in demand for these purposes. Basswood is valued highly for products made of wood in the natural state, particularly where a clean, attractive appearance and light weight are essential. Boxes and woodenware used for holding food are the main products.

Basswood lumber is manufactured from several species, but mainly from the species *Tilia americana*, which grows over nearly all of the eastern part of the United States. Other common names for this tree are linden, linn, bass, limetree, whitewood, and beetree. The species *Tilia heterophylla*, which is most commonly called white basswood and is found mainly in the Allegheny Mountain region, also

produces basswood lumber, principally in West Virginia, which is similar to that of *Tilia americana*. There are several other species of basswood in the United States, all of which have wood similar to the common basswood species, but contribute only small quantities of the timber. As the wood of these different species is very much alike, it is not kept separate in the market and is sold as basswood.

PROPERTIES OF THE WOOD.

GENERAL APPEARANCE.

The heartwood of basswood is creamy brown with occasional darker streaks. The sapwood is wide and not sharply defined from the heartwood. The wood has a very uniform appearance; the sapwood and, particularly, rapid-growth timber has a light-colored, clean look very desirable for special purposes. Basswood occasionally shows a curly growth, especially near the butt of the tree, which gives it an attractive appearance. This is unusual, however, and the wood does not normally possess a curly grain nor any figure, such as is found in oak and birch, for instance. It is therefore painted a uniform color or stained to imitate some other wood, when used for such purposes as inside house finish and the exterior woodwork of furniture.

PHYSICAL AND MECHANICAL PROPERTIES.

Basswood timber is light in weight, soft in texture, straight-grained, and has low strength values and poor shock-resisting ability in general comparison with other woods. Compared on the basis of density or weight, basswood has nearly average values for most of its properties, but has slightly greater stiffness and much greater shrinkage for its density than the average. In the classification of woods by the Forest Products Laboratory of the Forest Service into eight groups, according to results of tests for each of six physical and mechanical properties, basswood is described as follows:

Property:	Classification.
Density or weight	Light.
Strength as a beam or post	Weak.
Hardness	Soft.
Shock-resisting ability	Poor.
Stiffness	Moderately limber.
Shrinkage	Moderate.

Table 1 shows actual and comparative properties of basswood timber, as determined by the Forest Service from a very large number of tests. White oak is the wood generally used as a basis for comparison of properties. The composite values given are a combination of several kinds of tests. The hardness value of basswood is very low compared with white oak on this basis. This is also true of the different strength values, particularly shock-resisting ability.

TABLE 1.—*Actual and comparative properties of basswood timber.*

Locality where grown		Pennsylvania. Wisconsin.
Weight per cubic foot:		
Green	pounds	41
Air-dry	do	26
Kiln-dry	do	25
Specific gravity, oven-dry, based on volume when green		0.325
Shrinkage from green to oven-dry condition:		
In volume (1)	per cent	15.8
Radial (2)	do	6.6
Tangential (3)	do	19.3
Comparative shrinkage (twice volume plus radial plus tangential divided by 3)	per cent	15.8
Strength in bending at 12 per cent moisture: (4)		
Modulus of rupture	pounds per sq. in.	836.5
Relative strength compared with white oak (white oak=100)		56
Strength in compression parallel to grain at 12 per cent moisture: (5)		
Maximum crushing strength	pounds per sq. in.	4,542
Relative strength compared with white oak (white oak=100)		62
Shearing strength parallel to grain at 12 per cent moisture: (6)		
Shearing strength	pounds per sq. in.	1,000
Relative shearing strength compared with white oak (white oak=100)		49
Composite values:		
Strength as a beam or post		6,350
Compared with white oak (white oak=100)		61
Hardness		284
Compared with white oak (white oak=100)		27
Shock-resisting ability		5.48
Compared with white oak (white oak=100)		42
Stiffness		1,231
Compared with white oak (white oak=100)		81

NOTE.—Each of the composite values given in this table is a weighted average of several values derived from different kinds of strength tests. For instance, strength as a beam or post is a combination of values derived from tests in static bending, impact bending, and compression parallel to grain.

1=in volume; 2=radial; 3=tangential; 4=strength in bending; 5=strength in compression parallel to grain; 6=shearing strength parallel to grain.

Table 2 gives the relative properties of yellow poplar, cottonwood, and white pine compared with basswood, since these three woods are often put to the same uses as basswood. This table indicates that basswood is softer than any of these woods, also lighter in the oven-dry condition. In the green condition basswood is heavier than either yellow poplar or white pine because of the higher moisture content of the basswood. Cottonwood, however, is much heavier than basswood when green. Air-dry material of these four species does not differ greatly in weight. Basswood shrinks more than the other species given and its strength values are, in general, lower.

TABLE 2.—*Properties of yellow poplar, cottonwood, and white pine compared with basswood. Basswood=100.*

Species.	Weight.			Shrinkage from green to oven-dry condition.			Strength at 12 per cent moisture.		Composite values.			
	Oven-dry (specific gravity.)	Air-dry.	Green	In volume.	Radial.	Tangential.	Modulus of rupture in bending.	Compression parallel to grain (maximum crushing strength).	Strength as a beam or post.	Hardness.	Shock-resisting ability	Stiffness.
Yellow poplar..	112	104	93	72	62	74	105	111	114	128	103	116
Cottonwood....	112	108	120	89	59	99	96	105	102	119	134	98
White pine.....	109	104	95	49	33	63	102	119	116	128	109	100

Basswood is rated low in durability. The estimated average life of untreated basswood lumber, under conditions subjecting it to decay but not to mechanical wear, is placed at from 3 to 5 years. Its length of life in any particular case may, of course, vary from this, depending on conditions. If properly treated with coal tar creosote, or some other standard preservative, its durability may be greatly increased.[1]

STRUCTURE.

Basswood is a diffuse-porous wood (Pl. I). The pores are about uniform in size and quite evenly distributed throughout the annual-growth ring. They are, however, somewhat less numerous near the outer limits of each annual ring, and this makes a contrast with the greater number of pores at the beginning of each ring so that the growth rings can be quite readily distinguished on a smoothly cut transverse section. Medullary rays are generally not conspicuous on longitudinal surfaces; in some pieces, however, they are reddish and quite conspicuous on a quarter-cut surface; on a smoothly cut transverse section they can be readily distinguished without the aid of a lens.

IDENTIFICATION.

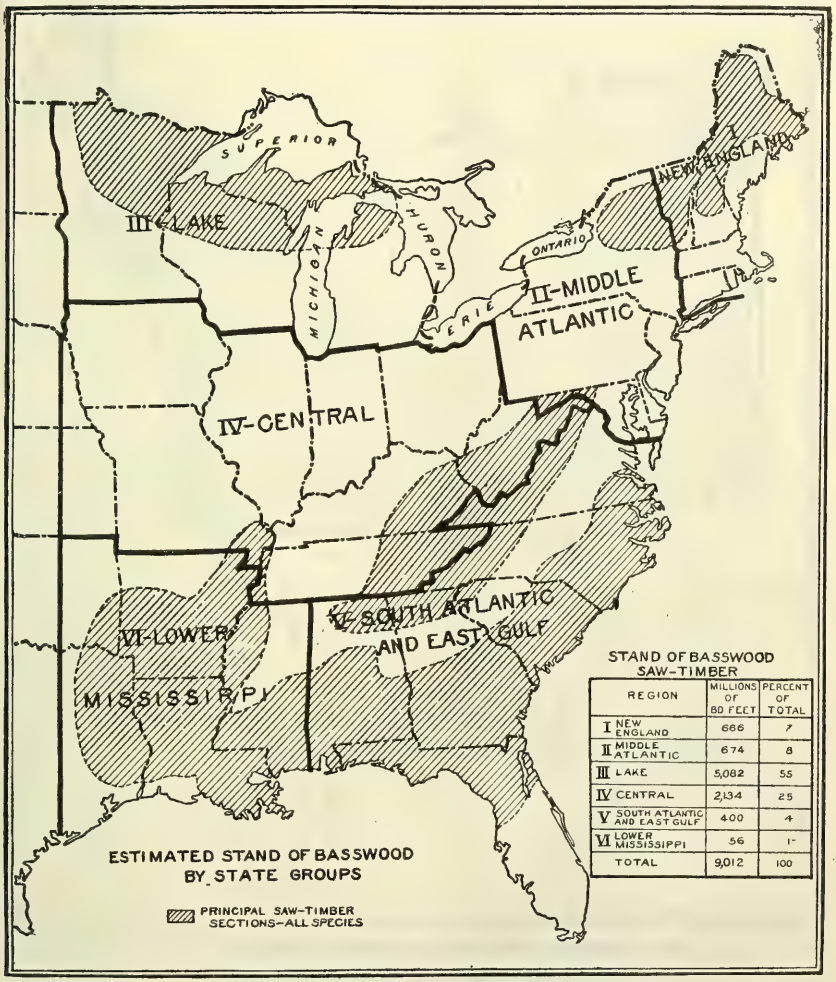
In appearance basswood resembles somewhat yellow poplar, cottonwood, buckeye, and tupelo. The yellow poplar, however, can be distinguished by its yellowish-brown heartwood, which has a characteristic greenish tinge. In cottonwood the medullary rays are very fine and barely visible even with a hand lens on a smoothly cut transverse surface, in contrast to those in basswood, which are visible to the unaided eye; the pores of cottonwood are conspicuously larger than those of basswood, as seen under a hand lens, and cottonwood generally has a "woolly" texture on sawed surfaces. In buckeye and tupelo the rays are also finer than in basswood. The brownish-black, longitudinal streaks occasionally found in the heartwood help to distinguish basswood.

[1] Farmers' Bulletin 744, Preservation of Farm timbers, gives methods of treatment.

SUPPLY.

Basswood timber grows in the eastern half of the United States, but it is not important near the Atlantic coast south of New England nor in the Gulf Coast States.

The estimated stand of basswood is given by regions in figure 1. The New England region contains approximately 666,000,000 board



STAND OF BASSWOOD SAW-TIMBER

REGION	MILLIONS OF BD FEET	PERCENT OF TOTAL
I NEW ENGLAND	666	7
II MIDDLE ATLANTIC	674	8
III LAKE	5,082	55
IV CENTRAL	2,134	25
V SOUTH ATLANTIC AND EAST GULF	400	4
VI LOWER MISSISSIPPI	56	1-
TOTAL	9,012	100

FIG. 1.—Estimated stand of basswood by State groups.

feet of timber, or 7 per cent of the supply. The middle Atlantic region, made up of the States of New York, Pennsylvania, New Jersey, Delaware, and Maryland, contains a trifle more. The Lake region, the most important region, contains more than one-half of all the basswood in the United States, or about 5,082,000,000 board feet. The second most important region, the central region, whose

greatest producing States are West Virginia, Tennessee, and Kentucky, contains a quarter of the basswood, while the South Atlantic and East Gulf and lower Mississippi regions contain less than 5 per cent of the supply. The region shown in figure 2 is estimated to contain about 98½ per cent of the total amount in the United States.

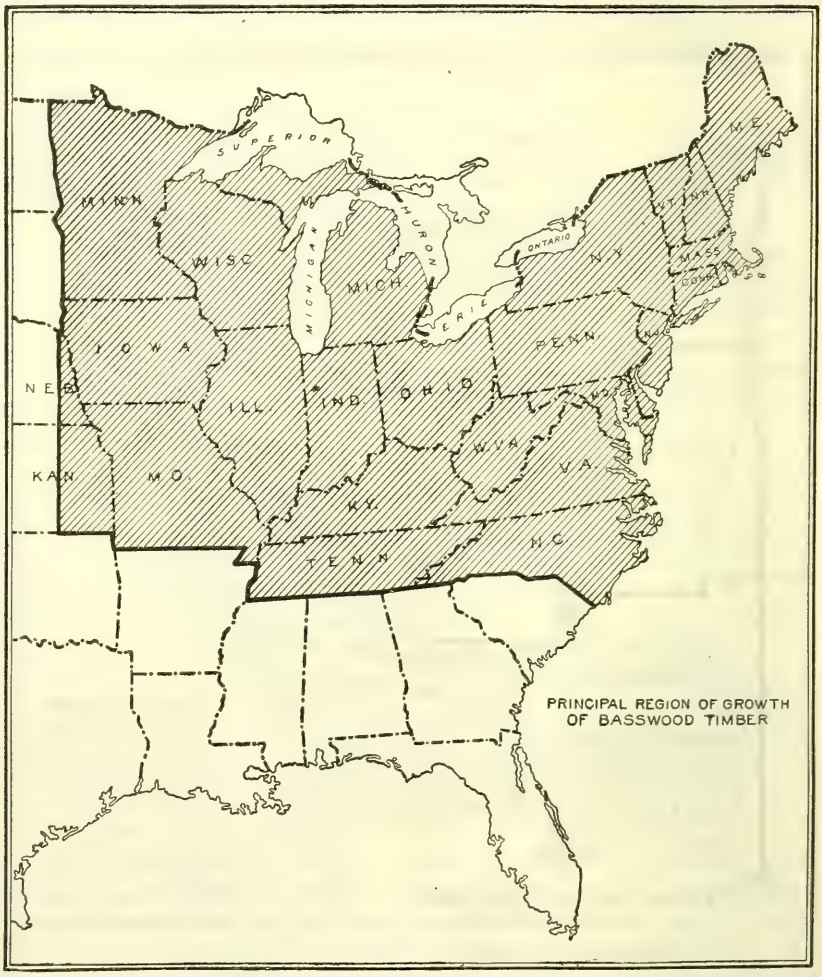


FIG. 2.—Principal region of growth of basswood timber (shaded area).

ANNUAL DRAIN ON THE SUPPLY.

The total present annual demand for basswood timber is difficult to determine, because of a lack of statistics for some of the industries using basswood logs as raw material. The total basswood lumber production for 1920 is placed at 195,000,000 board feet. Reports on veneer production in 1919, which are the latest available data, give 11,134,000 board feet, log scale, of basswood consumed in that year,

equivalent to about 13,000,000 board feet of lumber. In 1911, 33,042 cords of basswood were reported for excelsior, equivalent to about 16,500,000 board feet of lumber. Whether amounts now consumed are greater or less than these figures, and how much, can not be stated with certainty, because, although the demand for products of basswood from these industries has increased greatly, the supply of the timber has been more restricted in recent years. It is not safe, therefore, to assume any increase over these figures, especially since the sawmill cut of basswood lumber has suffered a considerable reduction during the period. Constant inroads have been made into the remaining stands of basswood to fulfill the increased demand. Smaller and in some cases second-growth timber has been cut so that both quantity and quality have been lowered.

Pulpwood statistics are available for the year 1920. The basswood reported as used for pulpwood during that year totaled 10,469 cords, equivalent to about 5,000,000 board feet of lumber. The number of sets of basswood slack-cooperage heading reported manufactured during the year 1919 was 3,078,000, equivalent to a little more than 6,000,000 board feet of lumber. These different items, which make up practically the entire demand for basswood timber, total about 235,000,000 board feet. It is probable, therefore, that the present annual drain upon the supply amounts to between 225,000,000 and 250,000,000 board feet. Assuming it is 250,000,000 board feet, the aggregate stand of basswood saw timber shown in figure 1 (9,012,000 board feet) without taking into consideration the growth that may take place during the period, will last approximately 40 years. If we are to continue using basswood provision will have to be made for growing trees to take the place of those cut. Natural growth not protected from fires while young will not fill the requirement gap toward the close of the 40-year period.

Little basswood is used for rough building construction, because it is not so strong as many lower-priced structural timbers, and it is not satisfactory in locations favorable to decay. Also, comparatively small quantities are used for fuel, because its heating value is low compared with other woods, such as beech and oak. Reports from wood-using industries of the United States obtained during the years 1909 to 1913 show an annual consumption of approximately 370,000,000 board feet of basswood lumber by factories. Adding to this the timber used for veneer, excelsior, pulpwood, and slack cooperage, brings the total to over 400,000,000 board feet, compared with 225,000,000 or 250,000,000 board feet, the probable present amount used. Evidently there has been a considerable reduction in the amount of basswood used during the past 10 years.

THE FUTURE OF BASSWOOD TIMBER.

The future of basswood depends upon provision made for new growth. Basswood is a very desirable tree to grow especially for the small timber owner who has a tract of woodland which he wishes to keep permanently forested. It is easily propagated, increases in size rapidly in comparison with other species, and is marketable in various forms. Rapid-growth timber yields the largest amount of the white sapwood, which is highly valued.

The tree grows well on deep, fresh or sandy loams, and has been known to grow rapidly and thriftily on very porous upland soils. It is generally a hardy tree, although on heavy upland soils it not only grows slowly but is likely to suffer injury during dry periods. The most favorable region for its growth is the northeastern part of the United States. In the virgin forest, basswood often reaches a height of 90 to 100 feet and a trunk diameter of 3 or 4 feet. When crowded by other trees it forms a straight stem, with but few branches, which are near the top (Pl. II); but when grown in the open the stem is short and there are many large branches.

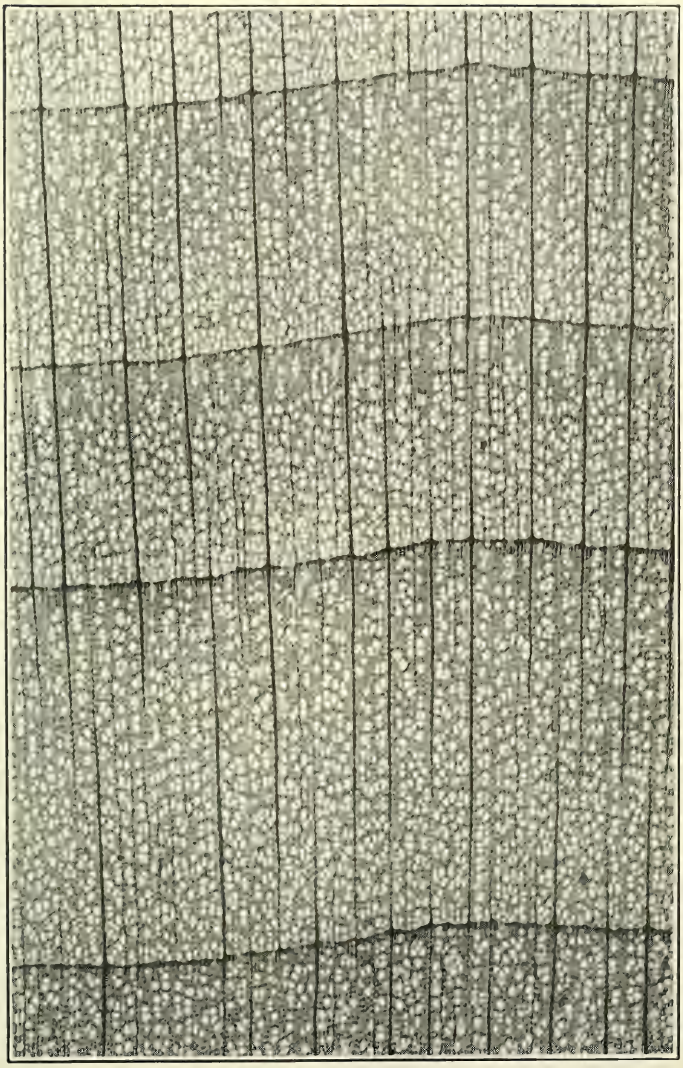
Basswood is one of the most prolific of our native trees in its sprouting capacity. The sprouts arise from the stump and afford a practical means of renewing basswood as a timber crop (Pl. III). To obtain vigorous sprouts the trees should be felled between November and March. The stumps should be cut low, so that the sprouts will start close to the ground, where they can soon develop a root system of their own and become self-supporting; otherwise, decay from the stump of the old tree is likely to enter them. Sprouts generally grow more rapidly than seedlings. For the production of small-diameter material, such as excelsior and pulpwood bolts, propagation by sprouting affords an excellent method of obtaining a timber crop in a comparatively short time.

The tree generally does not suffer severe injury from insect attack. Cattle like to browse upon the young twigs and leaves, however, and should be excluded from the young growth.

UTILIZATION BY INDUSTRIES.[2]

Wood-using industries generally belong in one of two classes, based on the form of raw material used: (1) Those which depend entirely upon the log or bolt, and (2) those which use mainly lumber or dimension stock for further manufacture into various products. The former class is termed primary and the latter secondary.

[2] Because of the low fuel value of the wood, basswood stands are of relatively inferior value as a source of firewood. As a shade tree and for ornamental planting, basswood is well liked because of its large crown and dense foliage. The tree is also valued very highly by beekeepers for the flowers, which are borne in great profusion. Honey made from basswood flowers is light-colored and of excellent quality; it generally goes under the name of poplar honey and brings a comparatively high price in the market.



CROSS SECTION OF BASSWOOD TIMBER MAGNIFIED 20 DIAMETERS.

LARGE BASSWOOD TREE CLEAR OF BRANCHES BUT AFFECTED WITH ROT FOR 20 TO 30 FEET UP AS INDICATED BY SWOLLEN BUTT.

THRIFTY BASSWOOD TREE WITH SEVERAL LARGE SPROUTS.

DEFECTS COMMONLY FOUND IN BASSWOOD TIMBER: A, END OF BASSWOOD LOG SHOWING DISCOLORED CENTRAL PORTION.

b, c, d, e, boards showing most common defects, dark and discolored wood, rotten streaks, and knots.

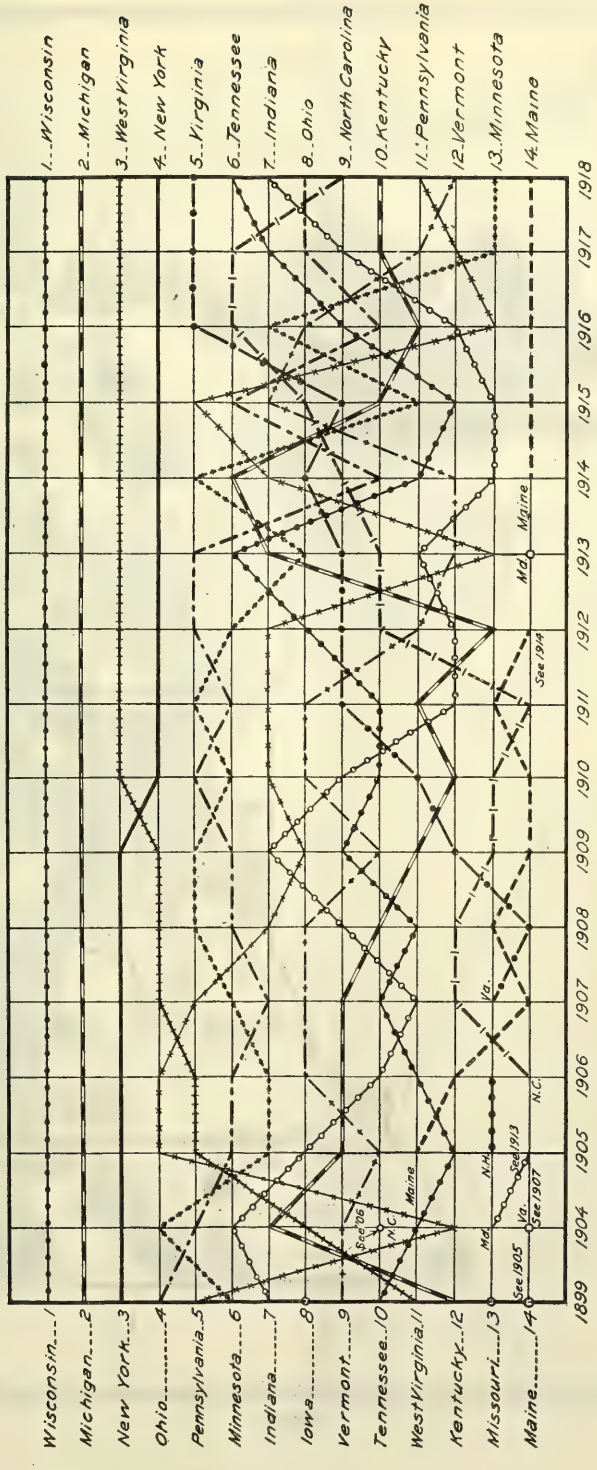


FIG. 3.—Rank of different States in manufacture of basswood lumber 1899–1918.

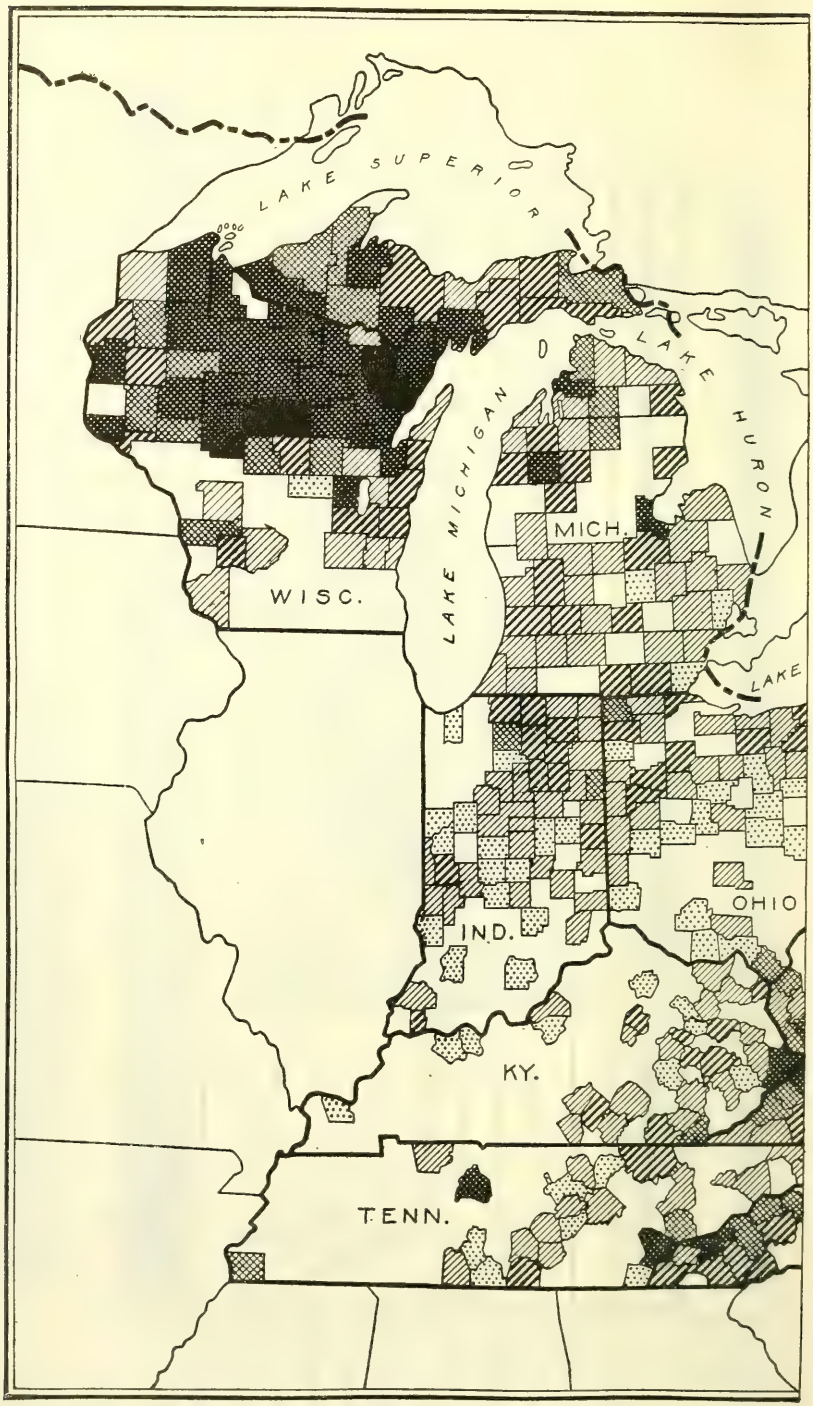

LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE
WISC.
MICH.
IND.
OHIO
KY.
TENN.

FIG. 4.

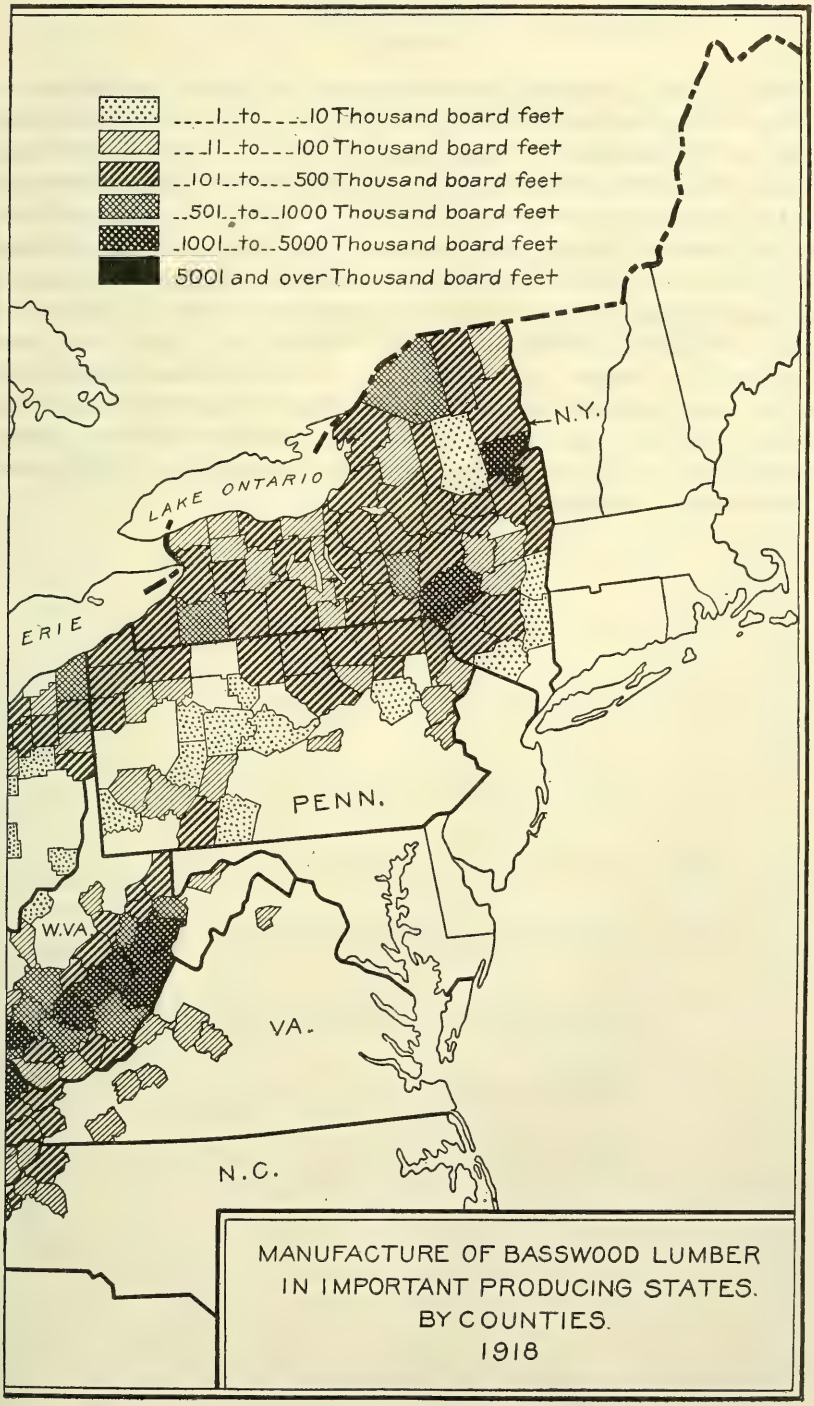

1 to 10 Thousand board feet
11 to 100 Thousand board feet
101 to 500 Thousand board feet
501 to 1000 Thousand board feet
1001 to 5000 Thousand board feet
5001 and over Thousand board feet
N.Y.
LAKE ONTARIO
ERIE
PENN.
W.VA.
VA.
N.C.
MANUFACTURE OF BASSWOOD LUMBER
IN IMPORTANT PRODUCING STATES.
BY COUNTIES.
1918

FIG. 4.

PRIMARY INDUSTRIES.

LUMBER.

Statistics on production.—Statistics on the annual production of basswood lumber are available for the year 1899 and for the years 1904 to 1920, inclusive. These data are given in Table 3, by States.

According to this table the 1920 production was only about one-half that of the annual production from 1906 to 1909, when the maximum cut of basswood lumber was reached. The figures for the different years are not all directly comparable, because in some years more of the smaller mills were included, as noted in the table. For several years, Wisconsin, Michigan, West Virginia, and New York have produced the largest quantities. In 1918 more than three-fourths of the total reported lumber cut of basswood was from these four States. Figure 3 shows the rank of the different States in lumber production in different years. Figure 4 shows the 1918 lumber production by counties.

TABLE 3.—*Reported annual production of basswood lumber, by States, in 1899, and from 1906 to 1920, inclusive (1,000 board feet), average value of the product, f. o. b. mills, and total number of mills reporting.*

Data.	1899	1906	1907	1908	1909	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920
Total number of mills reporting	31,833	22,398	28,850	31,231	[2] 46,584	[1] 31,934	[1] 28,107	[1] 29,648	[1] 21,668	[1] 27,506	[1] 16,815	[1] 17,269	[1] 16,420	[1] 14,753	[2] 29,534	15,978
Total number of mills cutting basswood	([3])	([3])	[4] 3,888	[4] 4,326	6,973	5,423	5,130	5,217	3,336	([3])	2,889	2,668	2,548	2,102	2,202	2,372
Average value per 1,000 board feet, f. o. b. mill	$12.84	$18.66	$20.03	$20.50	$19.50	$20.94	$19.20	$19.26	([3])	([3])	$18.89	$21.05	$25.96	$34.00	$40.03	$54.28
Computed total cut	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	260,000	275,000	203,000	200,000	.....	195,000
Total reported cut	308,069	376,838	381,088	319,505	399,151	344,704	304,621	296,717	257,102	264,656	207,607	209,275	190,757	174,661	183,562	169,276
Wisconsin	177,903	162,155	147,938	110,364	133,887	133,061	95,249	79,389	91,670	92,077	73,929	72,618	67,787	72,462	69,545	59,067
Michigan	45,796	73,458	60,859	49,832	69,453	59,899	47,572	53,533	39,265	43,568	28,718	36,756	38,427	29,788	33,532	23,562
West Virginia	1,872	17,480	26,904	19,632	29,679	28,936	36,213	32,986	31,623	31,992	26,956	28,955	21,098	17,195	15,296	19,369
New York	29,867	28,850	39,564	40,446	36,058	23,403	29,638	28,513	24,818	24,370	18,114	14,630	12,240	12,265	10,983	14,834
Virginia	401	1,684	3,384	3,700	9,658	8,012	8,809	9,343	6,231	7,779	5,131	7,030	6,925	5,895	7,591	7,258
Tennessee	2,331	8,274	8,463	6,408	11,463	8,500	8,354	9,460	8,703	7,257	4,668	5,107	6,251	5,013	4,353	4,953
Indiana	7,292	8,547	8,295	8,889	13,917	8,916	7,455	7,389	5,615	5,268	4,122	4,828	4,859	4,805	4,265	4,662
Ohio	12,512	12,718	14,480	16,282	16,007	15,116	11,482	14,920	8,784	7,288	7,914	5,049	5,231	4,775	7,363	4,940
North Carolina	273	2,020	5,079	3,891	6,387	6,079	4,273	8,128	6,180	7,447	6,129	7,028	6,570	4,718	5,071	7,616
Kentucky	1,453	9,436	8,609	8,091	10,056	7,340	8,214	6,986	8,404	8,692	4,979	4,833	4,698	4,249	4,671	4,303
Pennsylvania	10,073	17,932	18,835	13,502	13,008	11,568	11,303	10,925	5,237	8,324	8,075	4,194	4,391	3,437	5,681	4,417
Vermont	2,852	9,482	10,276	9,161	10,478	9,421	9,217	7,957	5,317	5,273	6,200	5,868	4,530	3,286	6,660	4,308
Minnesota	7,941	10,743	15,365	17,111	20,131	13,582	13,846	13,713	8,084	9,685	4,939	5,985	3,832	2,968	5,113	5,412
Maine	901	4,485	3,349	3,864	4,123	2,635	4,394	5,499	1,578	1,980	1,941	1,517	807	1,095	1,164	867
Maryland	140	1,674	608	1,063	2,386	580	1,743	1,157	1,978	692	1,236	896	393	677	7	166
New Hampshire	162	2,355	2,444	1,737	2,328	2,239	1,759	1,493	576	702	726	730	536	675	575	653
Iowa	4,302	1,435	2,572	1,843	4,111	1,869	2,103	2,257	1,296	574	1,754	1,393	896	507	788	947
Massachusetts	300	1,186	1,030	1,219	1,296	695	720	736	311	946	369	316	276	226	131	303
Connecticut	78	1,240	1,002	496	745	739	762	433	394	170	111	136	111	188	40	327
Arkansas	10	550	60	362	605	368	90	152	10	11	36	383	229	119	17	90
Illinois	243	434	647	303	587	357	102	90	118	19	51	106	103	101	44	59
Missouri	1,332	230	594	546	1,090	609	458	467	204	171	102	246	253	73	28	147
Georgia	35	35	125	104	88	118	60	277	300	60	115	285	.....	47	82	50
Alabama	.....	.....	336	259	564	461	425	560	141	275	140	183	176	32	12	19
Louisiana	.....	11	58	.....	.....	53	53	117	102	30	830	33	126	23	.....	229
Texas	.....	(a)	.....	7	97	20	116	.....	115	.....	47	61	.....	16	.....	32
New Jersey	.....	414	37	9	356	59	65	26	12	.....	25	14	4	13	.....	5
Oklahoma	.....	.....	.....	37	(a)	.....	.....	152	.....	5	100	30	.....	12	1	78
Mississippi	.....	.....	70	297	591	54	125	23	28	(a)	150	50	.....		449	603
All other States [5]	.....	1	105	50	2	15	21	36	8	1	.....	15	8		100	.....

[1] Mills cutting less than 50,000 feet excluded.
[2] Includes 4,543 mills cutting less than 50,000 feet in 1909 and 2,655 in 1919.
[3] Data not obtained.
[4] Mills in New York not included.
[5] Includes Kansas, Rhode Island, South Carolina, Florida, Delaware, and those marked "a."

TABLE 4.—*Number of mills in the different States reporting manufacture of basswood lumber in different years arranged in order of lumber cut for 1918.*

State.	1907	1908	1909	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920
Total	[1]3,888	[1]4,326	6,973	5,423	5,130	5,217	3,336	3,129	2,889	2,668	2,548	2,102	2,202	2,372
Wisconsin	573	627	763	631	538	572	375	298	286	269	273	259	251	225
Michigan	535	548	737	583	517	486	277	189	213	217	197	162	158	154
W. Virginia	274	295	422	348	340	326	165	240	191	187	161	141	137	138
New York	(2)	(2)	1,323	948	1,067	1,025	1,183	1,008	848	708	638	539	532	679
Virginia	(a)	98	174	171	147	107	74	61	55	57	73	57	56	56
Tennessee	146	173	191	143	151	146	99	126	71	59	82	63	(a)	70
Indiana	298	294	392	249	231	250	121	137	142	142	128	100	(a)	122
Ohio	321	404	575	447	393	460	205	198	191	174	174	138	141	165
N. Carolina	(a)	125	180	141	122	153	65	71	56	87	87	65	(a)	66
Kentucky	175	191	215	207	160	152	130	162	89	99	82	65	(a)	99
Pennsylvania	500	468	508	379	378	430	174	219	220	195	196	140	(a)	153
Vermont	259	260	280	280	279	279	128	143	177	163	174	117	(a)	127
Minnesota	188	230	352	264	240	251	124	88	73	66	70	77	(a)	104
Maine	(a)	135	144	118	136	154	56	60	82	74	55	44	(a)	(a)
Maryland	(a)	18	44	22	18	17	10	6	7	8	5	6	(a)	(a)
N. Hampshire	(a)	108	93	86	77	83	17	34	48	40	31	30	(a)	(a)
Iowa	(a)	77	181	111	98	109	46	13	49	41	42	28	(a)	(a)
Massachusetts	(a)	74	93	60	51	52	17	22	29	26	19	22	(a)	(a)
Connecticut	(a)	54	58	58	46	36	14	15	15	10	12	12	(a)	(a)
Arkansas	(a)	12	27	12	11	9	(a)	3	(a)	3	7	9	(a)	(a)
Illinois	(a)	42	48	32	21	17	12	5	5	10	9	4	(a)	(a)
Missouri	(a)	47	111	89	69	64	23	17	16	13	17	9	(a)	(a)
Georgia	(a)	19	11	14	8	6	3	(a)	(a)	3	.....	(a)	(a)	(a)
Alabama	(a)	8	16	17	17	19	7	11	8	5	9	(a)	(a)	(a)
Louisiana	(a)	.....	.....	(a)	(a)	(a)	(a)	(a)	4	(a)	4	(a)	(a)	(a)
Texas	.....	(a)	2	(a)	(a)	.....	3	.....	(a)	(a)	.....	3	(a)	(a)
New Jersey	(a)	4	16	7	7	5	(a)	.....	5	4	(a)	3	(a)	(a)
Oklahoma	.....	3	(a)	.....	.....	(a)	.....	.....	(a)	(a)	.....	(a)	(a)	(a)
Mississippi	(a)	10	16	3	3	(a)	(a)	(a)	3	(a)	.....	(a)	(a)	(a)
All other [3]	619	2	1	3	5	9	8	3	6	8	3	9	927	214

[1] Not including mills in New York.
[2] Not reported.
[3] Including Florida, Kansas, Rhode Island, South Carolina, and those marked "a."

TABLE 5.—*Percentage of basswood lumber manufactured by different classes of mills in 1918, also number of mills in different classes reporting.*

[Class 5 includes mills cutting 10,000,000 board feet and over per year; class 4, mills cutting from 5,000,000 to 9,999,000 board feet per year; class 3, 1,000,000 to 4,999,000 board feet; class 2, 500,000 to 999,000 board feet; class 1, 50,000 to 499,000 board feet.]

State.	Total.		Class 5.		Class 4.		Class 3.		Class 2.		Class 1.	
	Amount per cent.	Number of active mills reporting.	Amount per cent.	Number of mills.	Amount per cent.	Number of mills.	Amount per cent.	Number of mills.	Amount per cent.	Number of mills.	Amount per cent.	Number of mills.
United States	100	2,102	40	104	19	121	18	267	9	327	14	1,283
Wisconsin	100	259	59	40	13	21	15	42	6	34	7	122
Michigan	100	162	62	28	26	31	7	22	1	8	4	73
West Virginia	100	141	30	15	38	24	22	31	5	26	5	45
New York	100	539	0	0	1	3	17	20	24	67	58	449
Virginia	100	57	.....	1	[1] 72	9	13	8	9	17	6	22
Tennessee	100	63	43	5	34	9	13	11	3	5	7	33
Indiana	100	100	0	0	.....	1	[2] 78	32	10	17	12	50
Ohio	100	138	0	0	.....	2	[3] 35	20	42	36	23	80
North Carolina	100	65	14	3	35	8	28	13	12	10	11	31
Kentucky	100	65	.....	2	[4] 26	5	43	11	18	14	13	33
Pennsylvania	100	140	16	3	10	4	20	12	20	29	33	92
Vermont	100	117	0	0	0	0	17	8	27	30	55	79
Minnesota	100	77	.....	1	.....	1	[5] 20	4	4	6	76	65
All other States	100	179	2	6	14	3	26	33	23	28	35	109

[1] Includes cut of 1 mill in class 5.
[2] Includes cut of 1 mill in class 4.
[3] Includes cut of 2 mills in class 4.
[4] Includes cut of 2 mills in class 5.
[5] Includes cut of 1 mill in class 5 and 1 mill in class 4.

Table 4 gives the number of mills in the different States reporting the manufacture of basswood lumber in different years. New York, Pennsylvania, Vermont, Ohio, and Indiana produce relatively small amounts in proportion to the number of mills cutting basswood. Wisconsin and, to a lesser degree, Michigan produce relatively large amounts per mill cutting basswood.

Table 5 shows the proportionate amounts of basswood lumber manufactured by different size-classes of mills in different States in 1918. There has been a great reduction in the number of mills sawing basswood lumber for the last few years, particularly in Ohio, Indiana, and Pennsylvania, which indicates that the timber is largely cut out in those States.

Manufacture.—In sawing basswood lumber from the log, manufacturers generally try to get wide, clear stock, for which there is a demand. Such stock 2½ and 3 inches in thickness is often wanted for special uses. Basswood lumber that is all white brings a better price than when the brown wood is mixed with it.

Practically all basswood logs have a discolored central portion (Pl. IV, a), and lumber manufacturers generally saw as much wide, clear, white stock as possible from two sides of the log down to the discolored wood. Narrower stock is then sawed from the other two sides. Logs with large hollow or defective centers are sawed similarly. Such logs will yield as much according to the log scale as sound logs, because, in scaling, the central defective portion is deducted. The sound wood in such a log is often entirely clear; and, since the whiter wood is toward the outside, these logs generally produce a large percentage of high-grade stock. Probably the most common thicknesses of basswood lumber manufactured are 1, 2½, and 3 inches.

The quantities of different grades of basswood lumber sawed from logs naturally depend on the size and quality of the timber. Reports from several large mills in northern Michigan and Wisconsin indicate that the average proportions of different grades of basswood lumber produced are about as follows:

Grades:	Per cent.
Firsts and seconds	25
No. 1 common	30
No. 2 common	25
No. 3 common	20

The principal defects found in basswood lumber are black and rotten streaks and rotten knots (Pl. IV, b, c, d, e). Basswood timber has few knots, however, in comparison with most other hardwoods. The dark, brown-colored wood near the center of the log is not valued so highly as the light-colored wood, even though it may be perfectly sound and clear of defects (Pl. IV, a, b). Discoloration also often takes place in the white wood, which reduces its value. This

discoloration does not take place so readily in cold weather, and for this reason basswood is cut by some firms mainly in the winter or late fall. Some manufacturers claim that where the lumberyard is kept in proper condition, well drained and free from undergrowth, there is little trouble from the staining of basswood, whether cut in winter or summer. It is a common practice not to separate the white basswood from the brown until it has been air-dried for 6 summer months. The "stickers," or strips, used in piling lumber to keep the boards apart for drying may leave a discolored strip or band in basswood which is not removed in planing and lessens the value of the white wood for certain purposes. This is overcome by some firms by end-drying the lumber or pole-drying it for a week or two and then placing it in a "stuck" pile. In end-drying, the boards are placed on end under a specially built shed with stickers arranged horizontally at specified distances. Such a pile presents the appearance of an ordinary lengthwise lumber pile set on end. In this method the stickers are not brought into such close contact with the boards, since there is no weight or pressure. In pole-drying, the boards are piled almost vertically, crossing each other and supported by a strip of timber on which the lower edge of each board rests (Pl. V, figs. 1 and 2). Labor costs are greater in pole-drying than in the ordinary methods of piling lumber.

Basswood logs are very closely utilized in manufacturing into lumber, especially the outer clear, white, sound wood. Even the strips edged from the boards and called "bark strips" are often piled together and placed in stock. These bark strips are generally 1 inch thick and 2 to 4 inches wide, although some may be as wide as 6 inches. If of good color and free from defects, this stock is valuable to factories making small articles. Small strips of low-grade wood about 3 feet in length are sometimes sawed out and sold for crating.

Sawmill operators generally find it more profitable to manufacture lumber from their basswood logs than to sell the logs to factories.

Grades and prices.—Basswood logs are often separated into two grades, No. 1 or veneer logs, and No. 2, which is below the No. 1 grade. Veneer logs must be quite clear and of good form for rotary cutting. They must be at least 11 inches in diameter at the small end. No. 2 logs can be as small as 6 inches in diameter at the small end.

The National Hardwood Lumber Association grading rules for basswood lumber apply also to soft elm, soft maple, and buckeye. There are six grades: Firsts, seconds, selects, No. 1 common, No. 2 common, and No. 3 common.

Firsts must be 6 inches and over wide, 8 feet and over long. Pieces 4 to 9 square feet in size, surface measure, must be clear; pieces 10 to 15 square feet may have one standard defect or its equivalent; and

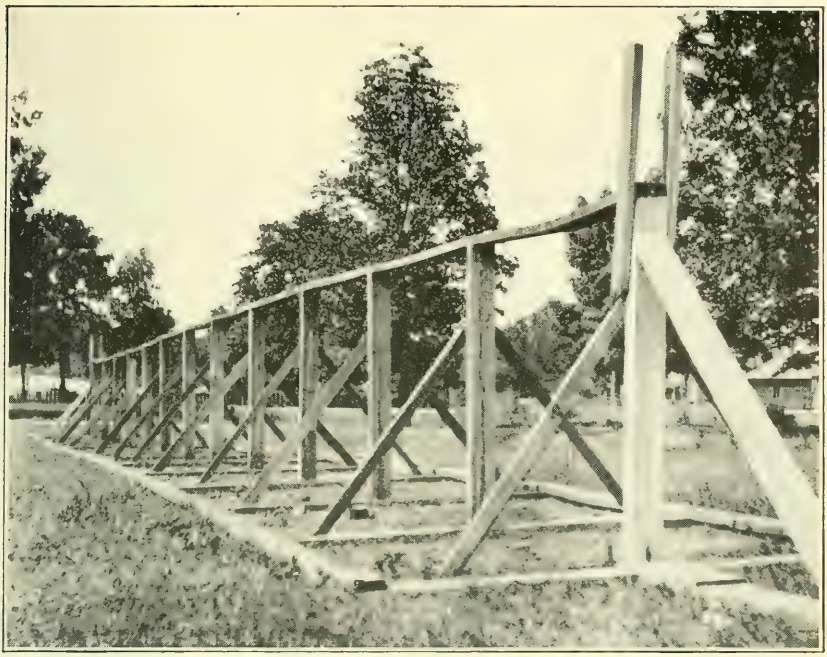


FIG. 1.—FRAMEWORK USED IN POLE DRYING.

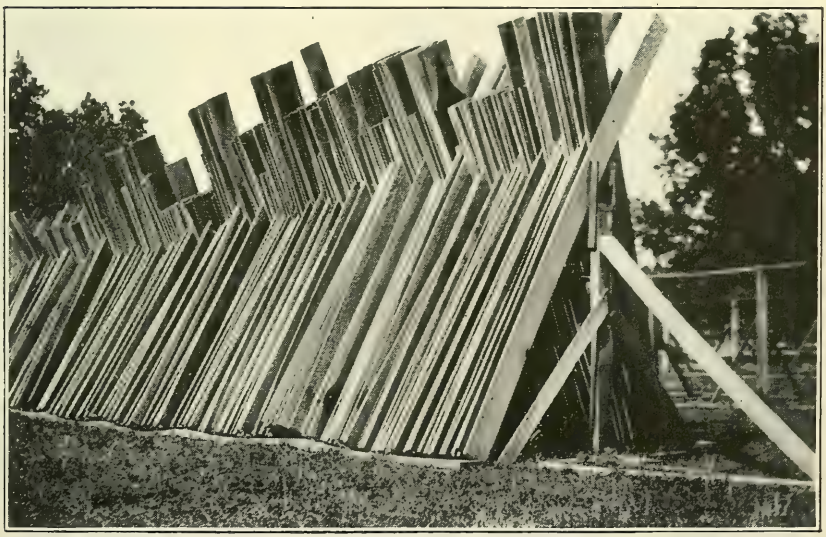
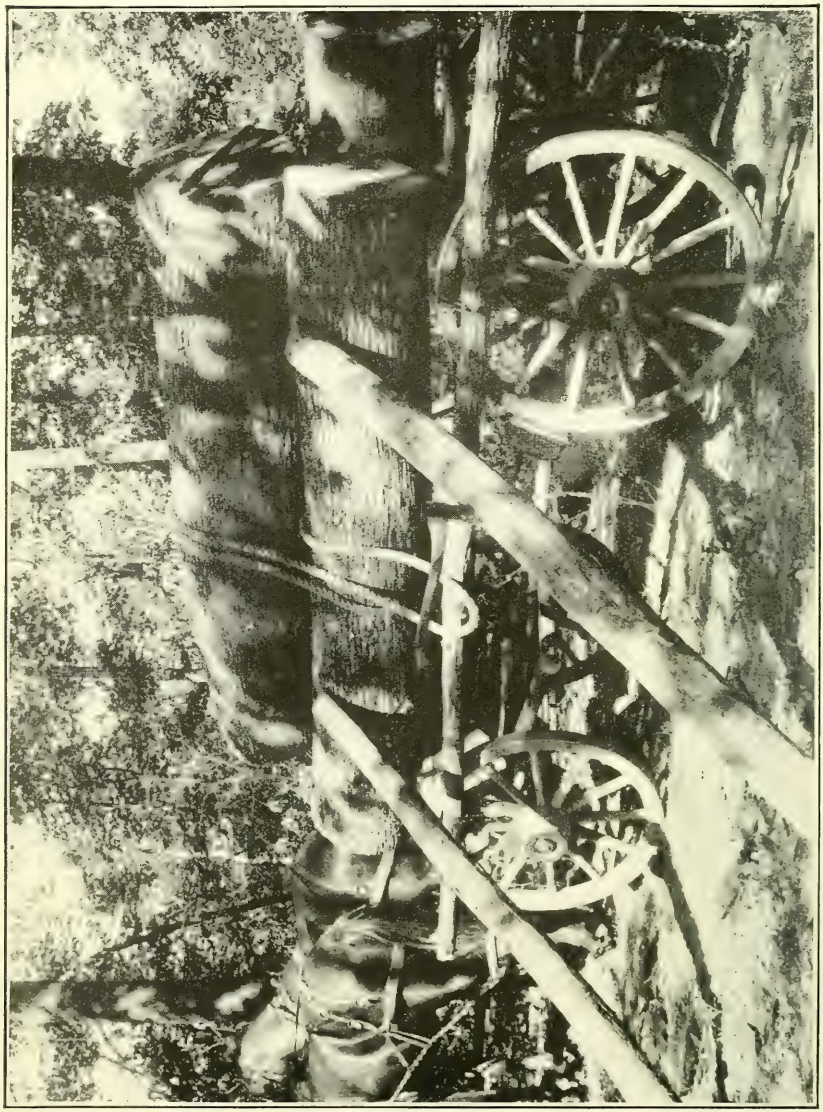


FIG. 2.—METHOD OF POLE-DRYING BASSWOOD LUMBER.



A WAGON LOAD OF BASSWOOD LOGS QUITE CLEAR AND FAIRLY STRAIGHT, SUITABLE FOR MANUFACTURE INTO VENEER. ABOUT 300 BOARD FEET OF LOGS MAKES A GOOD LOAD.

pieces 16 square feet and over may have two standard defects or their equivalent. Seconds are also 6 inches and over wide, and pieces can have from one to five standard defects or their equivalent for from 5 to 20 square feet, surface measure, as specified. Firsts and seconds are generally combined as one grade, called "firsts and seconds" and designated as FAS. In this combined grade there must be at least 20 per cent of firsts. Lengths are 8 to 16 feet, and there must be not more than 20 per cent under 12 feet long and not more than 10 per cent 8 and 9 feet long.

The grade "selects" includes pieces 4 inches and over wide and 6 feet and over long, with not more than 30 per cent under 12 feet long and not over 5 per cent of 6 and 7 foot lengths. In general the best face of pieces in selects must grade not below seconds and the reverse face not below No. 1 common. Admission into this grade also depends on amount of waste caused by defects in each piece.

Nos. 1, 2, and 3 common grades include pieces 3 inches and over wide and 4 feet and over long. No. 1 common must have not to exceed 5 per cent of 3-inch widths, with not over 30 per cent shorter than 10 feet, and not to exceed 10 per cent of 4 and 5 foot lengths. Pieces 4 and 5 feet long, also pieces 3 and 4 inches wide and 6 and 7 feet long, must be clear of defects. Other pieces must work at least 66⅔ per cent clear face in from one to four cuttings of specified minimum sizes, depending on the dimensions of the pieces. No. 2 common must have not more than 10 per cent of 4 and 5 foot lengths. Pieces must work at least 50 per cent sound in not more than three to five cuttings, depending on the size of the piece. Cuttings must be at least 3 inches wide by 2 feet long. Pieces in No. 3 common grade must contain at least 25 per cent of sound cuttings, each of which must have a minimum width of 1½ inches and a minimum surface area of 36 square inches. It is specifically noted in these rules that black spots and black streaks are defects in all grades, and care must be exercised in estimating their damage, for if any piece has an excessive amount its grade will be lowered.

Table 6 gives average stumpage values of basswood timber for the years 1907 and 1912. These are averages of reports from a large number of timberland owners. Table 7 gives prices based on many reports of actual sales of stumpage in 1912. Prices of maple, birch, and beech are included for comparison. Reports obtained on stumpage sales in 1920 indicate a considerable increase in prices. Selling prices for Michigan and Wisconsin averaged $10, and an average selling price of $19.40 was reported on sales of basswood stumpage in Ohio. This high figure for Ohio probably includes small lots of choice timber. Reports on sales in States where the timberland has been largely cut over show much variation in price. Basswood is generally purchased together with other hardwood timber, such as

yellow poplar, maple, and oak, with which it is found in mixture, and the price varies greatly. Prices ranging from $2.50 to $10 a thousand board feet for mixed stands were reported from Kentucky, Tennessee, and West Virginia. The average value of basswood lumber per 1,000 board feet f. o. b. mills, obtained from reports of sawmills on lumber production, is given in Table 8, by States, for those years in which the data were collected. With the exception of the years 1909, 1911, and 1915, this table shows a continuous increase in value; increasingly higher values are shown since the year 1915. Average prices in Kentucky, Tennessee, and North Carolina are generally $1 or $2 a thousand board feet below the average.

TABLE 6.—*Average stumpage values of basswood for 1907 and 1912, from reports on values from timberland owners.*

	1907	1912
Northeastern States:		
Maine	$5.80 (20)	$6.04 (48)
New Hampshire	6.25 (18)	7.56 (23)
Vermont	4.96 (27)	6.90 (25)
New York	8.31 (21)	8.51 (88)
Pennsylvania	7.59 (41)	8.14 (61)
Average of 5 States	6.68 (127)	7.68 (245)
North Central States:		
Ohio	9.59 (27)	11.59 (59)
Indiana	10.83 (27)	11.22 (43)
Average of 2 States	10.21 (54)	11.43 (102)
Southern Appalachian States:		
Maryland	4.50 (3)	4.50 (4)
Virginia	3.33 (6)	6.33 (4)
West Virginia	3.91 (43)	4.11 (9)
Kentucky	4.46 (3)	4.62 (25)
Tennessee	4.04 (12)	4.22 (18)
North Carolina	1.67 (6)	3.30 (23)
Average of 6 States	3.75 (73)	4.16 (82)
Lake States:		
Michigan—		
Upper Peninsula	5.61 (23)	.....
Lower Peninsula	8.95 (59)	.....
Southern tier of counties	1.67 (6)	.....
State average	8.26 (88)	9.57 (86)
Wisconsin	6.59 (65)	7.12 (122)
Minnesota	5.50 (10)	7.41 (39)
Average of 3 States	7.42 (163)	8.02 (247)

The numerals in parentheses indicate the number of reports on which the averages are based. (From Department of Agriculture Bulletin 285, The Northern Hardwood Forest, Table 12.)

TABLE 7.—*Comparative stumpage values per 1,000 board feet of basswood, maple, birch, and beech, 1912.*

[From reports of sales collected by the Forest Service.]

Species.	Northeastern States.[1]	Southern States.[2]	Lake States.[3]
Basswood	$8.40	$4.92	$6.30
Maple	5.98	3.45	4.58
Birch	5.61	3.33	4.85
Beech	4.38	2.86	3.67

[1] Maine, New Hampshire, Vermont, Massachusetts, New York, and Pennsylvania.
[2] Maryland, Virginia, West Virginia, Kentucky, Tennessee, and North Carolina.
[3] Minnesota, Wisconsin, and Michigan.

TABLE 8.—*Average value of basswood lumber per 1,000 board feet f. o. b. mills, by States, for different years.*

	1899	1904	1907	1909	1911	1915	1916	1917	1918	1919	1920
United States	$12.84	$16.86	$20.03	$19.50	$19.20	$18.89	$21.05	$25.96	$34.00	$40.03	$54.28
Wisconsin	12.67	16.12	19.62	18.97	19.03	18.94	21.15	26.60	34.68	39.78	57.05
Michigan	13.08	17.29	20.31	21.16	20.17	19.57	22.07	27.74	36.04	42.38	56.65
West Virginia	12.10	18.09	19.60	20.07	18.56	19.13	20.82	25.43	35.34	40.86	60.81
New York	14.24	17.76	24.00	17.88	20.81	19.50	22.98	25.48	33.12	40.36	50.44
Virginia	10.21	20.10	19.15	18.27	15.83	18.81	21.18	25.65	36.13	37.54	64.16
Tennessee	10.09	14.97	17.86	19.28	19.80	17.26	19.76	25.21	32.00	.....	52.87
Indiana	14.74	32.71	22.27	24.38	20.40	21.31	22.80	27.49	34.13	.....	53.24
Ohio	12.21	18.21	20.70	22.82	20.36	19.39	22.07	25.84	32.34	49.17	50.14
North Carolina	12.34	10.13	17.74	16.57	19.33	18.24	19.83	22.96	30.09	.....	44.81
Kentucky	9.79	13.20	18.69	18.11	19.19	18.46	18.07	23.41	28.94	.....	42.36
Pennsylvania	13.34	20.72	20.20	21.63	20.23	17.30	20.52	23.69	29.33	.....	53.59
Vermont	12.65	16.37	17.26	17.07	19.22	17.71	19.27	23.68	32.33	.....	44.88
Minnesota	10.63	13.10	17.72	17.10	15.67	16.10	17.15	19.45	23.11	.....	38.69
Maine	11.09	15.42	18.36	17.02	18.00	17.13	17.67	20.54	18.82	.....	.....
Maryland	11.57	18.67	17.09	15.96	16.00	20.00	18.14	29.16	30.19	.....	.....
New Hampshire	9.68	18.56	17.47	16.20	19.33	17.66	18.34	22.00	31.30	.....	.....
Iowa	13.12	16.97	19.37	19.53	18.79	19.41	20.73	23.02	25.53	.....	.....
Massachuetts	9.98	11.00	17.61	16.71	18.79	15.21	18.07	20.38	26.49	.....	.....
Connecticut	26.28	12.00	18.24	17.88	18.50	17.88	19.01	16.86	22.46	.....	.....
Arkansas	10.00	.....	17.10	21.94	.....	20.00	20.38	18.21	21.22	.....	.....
Illinois	13.19	23.75	19.74	16.94	19.00	18.75	17.30	20.79	32.50	.....	.....
Missouri	11.18	14.33	14.38	16.61	14.62	16.88	17.87	18.42	23.33	.....	.....
Georgia	10.71	.....	12.68	15.02	17.33	20.09	18.18	.....	35.00	.....	.....
Alabama	.....	10.12	18.72	19.93	18.50	18.36	21.37	20.61	25.06	.....	.....
Louisiana	.....	.....	20.69	.....	.....	16.37	16.61	16.59	18.48	.....	.....
Texas	.....	.....	.....	18.00	.....	18.00	18.75	.....	26.44	.....	.....
New Jersey	.....	16.00	23.54	26.75	.....	19.60	16.00	30.00	25.00	.....	.....
Oklahoma	.....	.....	.....	16.50	.....	15.00	14.00	.....	27.67	.....	.....
Mississippi	.....	.....	22.50	18.38	.....	.....	15.50	.....	22.00	.....	.....
South Carolina	.....	19.25	.....	.....	.....	.....	.....	.....	.....	.....	.....
Rhode Island	.....	.....	13.95	.....	.....	.....	.....	.....	.....	.....	.....
Kansas	.....	.....	.....	.....	.....	.....	18.75	.....	.....	.....	.....
Florida	.....	.....	.....	.....	.....	.....	.....	35.00	.....	.....	.....

TABLE 9.—*Average wholesale prices of basswood lumber per thousand board feet f. o. b. mill in Wisconsin and Michigan, by grades, for different years.*

	1909	1910	1911	1912	1913	1914	1915	1916
Wisconsin:								
Firsts and seconds 4/4	$35.72	$34.66	$33.81	$34.51	$37.45	$36.20	$33.79	$36.08
No. 1 common 4/4	24.93	23.97	2[illegible].85	23.58	24.97	24.68	22.95	25.07
No. 2 common 4/4	14.98	14.31	13.76	16.04	19.50	17.94	15.61	17.18
No. 3 common 4/4	11.96	.....	.....	.....	17.30	15.51	13.05	13.99
Mill run	21.72	21.45	19.03	18.81	25.05	20.95	19.38	.....
Michigan:								
Firsts and seconds 4/4	36.34	35.87	36.37	35.82	37.78	36.48	35.27	37.88
No. 1 common 4/4	26.29	25.88	25.46	24.87	27.11	26.63	25.05	27.67
No. 2 common 4/4	18.24	17.19	16.54	16.68	19.69	19.66	18.33	18.55
No. 3 common 4/4	13.92	.....	.....	.....	17.57	17.34	14.50	15.87
Mill run	22.96	22.12	20.17	20.06	23.03	20.94	20.34	21.08

TABLE 10.—*Average wholesale prices per 1,000 board feet of different grades and thicknesses of basswood lumber at representative markets for different years and quarter years.*

Market and grade.	1912	1913	1914	1915	1916	1917	1918				1919				1920				1921			
							First quarter.	Second quarter.	Third quarter.	Fourth quarter.	First quarter.	Second quarter.	Third quarter.	Fourth quarter.	First quarter.	Second quarter.	Third quarter.	Fourth quarter.	First quarter.	Second quarter.	Third quarter.	Fourth quarter.
New York:																						
Firsts and seconds 4/4	$41.88	$43.00	$42.00	$41.33	$44.75	$53.08	$59.67	$62.33	$66.00	$66.00	$66.00	$68.67	$76.83	$91.67	$132.33	$150.83	$126.50	$132.00	$108.66	$92.00	$88.00	$88.67
No.1 common 4/4	31.75	33.00	32.00	31.33	33.08	42.92	48.67	50.33	54.00	54.00	54.00	55.00	60.17	67.00	106.33	122.83	102.50	107.00	87.00	62.00	56.00	54.00
No.1 common 6/4	34.75	36.00	35.00	34.33	36.08	46.75	52.00	52.33	56.00	56.00	56.00	57.00	62.17	69.00	112.00	127.83	107.50	112.00	92.00	67.00	61.00	59.00
No.1 common 8/4	36.75	38.00	37.00	36.33	38.08	49.25	57.00	57.33	61.00	61.00	61.00	62.00	67.17	74.00	117.00	132.83	112.50	117.00	97.00	72.00	66.00	64.00
No.2 common 4/4	22.71	25.00	24.83	24.33	25.75	33.08	36.67	40.33	42.00	42.00	42.00	42.33	45.83	50.00	69.67	83.50	68.50	68.67	47.00	40.33	36.00	34.00
Buffalo:																						
Firsts and seconds 4/4	38.13	39.25	38.25	38.25	40.75	51.17	58.17	60.83	65.00	65.00	65.00	67.67	75.50	90.17	130.50	149.17	125.50	130.00	106.67	90.00	86.00	86.67
No.1 common 4/4	28.00	29.25	28.25	28.25	29.08	41.00	47.17	48.83	53.00	53.00	53.00	54.00	58.83	65.50	104.50	120.83	100.50	105.00	85.00	60.00	54.00	52.00
No.1 common 6/4	31.00	32.25	31.25	31.25	32.08	44.84	50.50	50.83	55.00	55.00	55.00	56.00	60.83	67.50	110.17	125.83	105.50	110.00	90.00	65.00	59.00	57.00
No.1 common 8/4	33.00	34.25	33.25	33.25	34.08	47.34	55.50	55.83	60.00	60.00	60.00	61.00	65.83	78.50	118.17	130.83	110.50	115.00	95.00	70.00	64.00	62.00
No.2 common 4/4	18.96	22.00	22.08	22.08	22.75	31.00	33.17	36.50	38.00	39.00	41.00	41.33	44.67	49.17	68.17	81.50	66.50	66.67	45.00	38.33	34.00	32.00
Cleveland:																						
Firsts and seconds 4/4	38.13	39.25	38.25	38.25	40.75	50.75	57.67	60.33	64.50	64.50	64.50	67.17	75.00	85.67	128.25	148.17	124.50	129.00	105.67	89.00	85.00	85.67
No.1 common 4/4	28.00	29.25	28.25	28.25	29.08	40.58	46.67	48.33	52.50	52.50	52.50	53.50	58.33	69.00	104.25	119.83	99.50	104.00	84.00	59.00	53.00	51.00
No.1 common 6/4	31.00	32.25	31.25	31.25	32.08	44.42	50.00	50.33	54.50	54.50	54.50	55.50	60.33	71.00	107.75	124.83	104.50	109.00	89.00	64.00	58.00	56.00
No.1 common 8/4	33.00	34.25	33.25	33.25	34.08	46.92	55.00	55.33	59.50	59.50	59.50	60.50	65.33	75.00	112.25	129.83	109.50	114.00	94.00	69.00	63.00	61.00
No.2 common 4/4	18.96	21.25	21.08	21.08	21.75	30.83	34.67	38.33	40.50	40.50	40.50	40.83	44.17	48.50	67.50	80.50	65.50	65.67	44.00	37.33	33.00	31.00
Detroit and Grand Rapids:																			Grand Rapids only.			
Firsts and seconds 4/4	31.13	38.25	37.25	36.58	39.75	48.08	54.67	57.33	60.50	60.50	60.50	63.17	71.00	85.67	[1]127.67	[1]147.17	[1]123.50	[1]127.00	103.67	97.00	98.00	98.67
No.1 common 4/4	27.00	28.25	27.25	26.58	28.08	37.92	43.67	45.33	48.50	48.50	48.50	49.50	54.33	61.00	[1]101.67	[1]118.83	[1] 98.50	[1]102.00	82.00	57.00	51.00	49.00
No.1 common 6/4	30.00	31.25	30.25	29.58	31.08	41.75	47.00	47.33	50.50	50.67	51.00	52.00	56.50	63.00	[1]107.33	[1]123.83	[1]103.50	[1]107.00	87.00	62.00	56.00	54.00
No.1 common 8/4	32.00	33.25	32.25	31.58	33.08	44.25	52.00	52.33	55.50	55.67	56.00	57.00	61.50	68.00	[1]112.33	[1]128.83	[1]108.50	[1]112.00	92.00	67.00	61.00	59.00
No.2 common 4/4	17.96	20.25	20.08	19.58	20.75	28.08	31.67	35.33	36.50	36.50	36.50	36.83	40.17	44.50	[1] 65.17	[1] 69.50	[1] 54.50	[1] 63.67	42.00	35.33	31.00	29.00

Chicago:																						
First sand seconds 4/4	37.13	38.25	37.25	36.58	39.75	48.08	54.67	57.33	60.50	60.50	60.50	63.17	71.00	85.67	126.33	145.17	121.50	124.00	100.67	84.00	80.00	80.67
No.1 common 4/4	27.00	28.25	27.25	26.58	28.08	37.92	43.67	45.33	48.50	48.50	48.50	49.50	54.33	61.00	101.00	117.83	97.50	99.00	79.00	54.00	48.00	46.00
No.1 common 6/4	30.00	31.25	30.25	29.58	31.08	41.75	47.00	47.33	50.50	50.67	51.00	52.00	56.50	63.00	106.00	121.83	101.50	104.00	84.00	59.00	53.00	51.00
No.1 common 8/4	32.00	33.25	32.25	31.58	33.08	44.25	52.00	52.33	55.50	55.67	56.00	57.00	61.50	68.00	111.00	126.83	106.50	109.00	89.00	64.00	58.00	56.00
No.2 common 4/4	19.96	20.25	20.08	19.58	20.75	28.08	31.67	35.33	36.50	36.50	36.50	36.83	40.17	44.50	63.83	77.50	62.50	60.67	39.00	32.33	28.00	26.00
Minneapolis and St. Paul:																						
Firsts and seconds 4/4	37.13	38.25	37.25	37.17	40.75	48.08	54.67	57.33	60.50	60.50	60.50	63.17	71.00	85.67	126.33	145.17	121.50	124.00	100.67	84.00	80.00	80.67
No.1 common 4/4	27.00	28.25	27.25	27.17	29.08	37.92	43.67	45.33	48.50	48.50	48.50	49.50	54.33	61.00	100.33	116.83	96.50	99.00	79.00	54.00	48.00	46.00
No.1 common 6/4	30.00	31.25	30.25	30.17	32.08	41.75	47.00	47.33	50.50	50.50	50.50	51.50	56.33	63.00	106.33	122.33	102.00	104.00	84.00	59.00	53.00	51.00
No.1 common 8/4	32.00	33.25	32.25	32.17	34.08	44.25	52.00	52.33	55.50	55.50	55.50	56.50	61.33	68.00	111.33	127.33	107.00	109.00	89.00	64.00	58.00	56.00
No.2 common 4/4	17.96	19.67	20.08	20.17	21.75	28.08	31.67	35.33	37.83	37.83	36.50	36.83	40.17	44.50	63.83	77.50	62.50	60.67	39.00	32.33	28.00	26.00
Wausau, Wis.:																						
Firsts and seconds 4/4	34.63	35.63	34.75	34.08	37.25	45.58	54.67	54.83	57.50	57.50	57.50	60.17	68.00	82.67	123.00	141.67	118.00	120 00	96.67	80.00	76.00	76.67
No.1 common 4/4	24.50	25.63	24.75	24.08	25.58	35.42	43.67	42.83	45.50	45.50	45.50	46.50	51.33	58.00	97.00	113.33	93.00	95.00	75.00	50.00	44.00	42.00
No.1 common 6/4	27.50	28.63	27.75	27.08	28.58	39.25	47.00	44.83	47.50	47.50	47.50	48.50	53.33	60.00	102.67	118.33	98.00	100.00	80.00	55.00	49.00	47.00
No.1 common 8/4	29.50	30.63	29.75	29.08	30.58	41.75	52.00	49.83	52.50	52.50	52.50	53.50	58.33	65.00	107.67	123.33	103.00	105.00	85.00	60.00	56.00	55.00
No.2 common 4/4	15.46	17.75	17.58	17.67	19.08	25.58	31.67	32.83	33.50	33.50	33.50	33.83	37.17	41.50	60.50	74.00	59.00	56.67	35.00	28.33	24.00	22.00
St. Louis:																						
Firsts and seconds 4/4	39.13	40.25	39.25	38.58	41.75	50.42	57.17	59.83	64.00	64.00	64.00	66.67	74.17	84.67	127.67	147.67	124.00	128.00	104.67	88.00	84.00	84.67
No.1 common 4/4	29.00	30.25	29.25	28.58	30.08	40.25	46.17	47.83	52.00	52.00	52.00	53.00	57.50	68.00	104.33	119.33	99.00	103.00	83.00	58.00	52.00	50.00
No.1 common 6/4	32.00	33.25	32.25	31.58	34.08	44.25	49.50	49.83	54.00	54.00	54.00	55.00	59.50	70.00	110.00	124.33	104.00	108.00	88.00	63.00	57.00	55.00
No.1 common 8/4	34.00	35.25	34.25	33.58	35.08	46.58	54.50	54.83	59.00	59.00	59.00	60.00	64.50	71.00	113.67	129.33	109.00	113.00	93.00	68.00	62.00	60.00
No.2 common 4/4	19.96	22.25	22.08	21.58	22.75	30.42	34.17	37.83	40.00	40.00	40.00	40.33	43.33	47.50	66.50	80.00	65.00	64.67	43.00	36.33	32.00	30.00

[1] Grand Rapids only.

TABLE 11.—*Average wholesale prices of basswood and yellow poplar for different years and quarter-years, 4/4 inch, No. 1 common grade at Chicago.*

Year.	Basswood.	Yellow poplar.	Year.	Basswood.	Yellow poplar.
1912	$27.00	$34.88	1919:		
1913	28.25	34.71	First quarter	$48.50	$55.17
1914	27.25	32.67	Second quarter	49.50	56.50
1915	26.58	31.25	Third quarter	54.33	63.50
1916	28.08	33.25	Fourth quarter	61.00	72.67
1917:			1920:		
First quarter	33.17	34.50	First quarter	101.00	106.67
Second quarter	40.17	38.17	Second quarter	117.83	123.00
Third quarter	35.67	39.50	Third quarter	97.50	107.50
Fourth quarter	42.67	41.00	Fourth quarter	99.00	86.67
1918:			1921:		
First quarter	43.67	42.67	First quarter	79.00	75.00
Second quarter	45.33	45.50	Second quarter	54.00	55.67
Third quarter	48.50	49.33	Third quarter	48.00	49.33
Fourth quarter	48.50	56.50	Fourth quarter	46.00	54.67

TABLE 12.—*Production of basswood veneer.*

Year.	Wood used, log scale.	Veneer produced.			Cost per 1,000 feet.
		Rotary.	Sawed or sliced.	Total.	
	M feet.	*M sq. ft.*	*M sq. ft.*	*M sq. ft.*	
1905	11,376			82,925	
1906	15,659	72,158	1,285	73,443	$15.84
1907	13,561	75,203	2,790	77,993	18.00
1908	11,609				20.16
1909	13,715				20.20
1910	11,003				
1911	11,602				
1919	11,134				

TABLE 13.—*Consumption of basswood for veneer, by States and years, in thousand board feet.*

State.	1906	1907	1908	1909
Wisconsin	8,979	7,480	4,929	5,783
Michigan	2,699	2,282	1,686	3,660
Maine	1,505	1,377	2,204	1,199
New York	1,132	620	864	1,139
Indiana	150	365	785	482
Ohio	146	720	300	428
Vermont	25	131	330	175
Pennsylvania	136	239	246	163
West Virginia	100	64	29	90
Kentucky	24	40	80	50
North Carolina			30	25
Missouri	200	10		10
Tennessee	100	100	12	8
New Jersey	152	8		3
Mississippi			50	
Georgia			15	
Maryland			10	
Virginia	50	75		
Alabama		50		
Arkansas	260			
Illinois	1			
Total	15,659	13,561	11,609	13,715

In Table 9 are given average wholesale prices of different grades of basswood lumber per 1,000 board feet f. o. b. mill in Wisconsin and Michigan for the years 1909 to 1916, as reported by sawmills in those States.

Table 10 gives prices of 4/4 firsts and seconds, of 4/4, 6/4, and 8/4 No. 1 common and of 4/4 No. 2 common from 1912 to 1920, in different markets, as published by the Lumberman's Bureau. For comparsion Table 11 gives prices, from the same source, of 4/4 No. 1 common basswood and yellow poplar at Chicago.

VENEER.

Statistics on production.—Table 12 gives available statistics of the Census on the production of basswood veneer for different years. The quantities of veneer produced and the costs are included, where reported. The consumption of basswood for veneer, by States, is given in Table 13 for the years 1906 to 1909, inclusive, which are the only years for which these data are available. Wisconsin and Michigan were the main States producing basswood veneer in 1909; and they are also the main producing States at the present time, because the main timber supply is located in this region.

Manufacture.—Basswood is converted into veneer almost entirely by the rotary process. Logs for veneering should be at least 10 inches in diameter at the small end and reasonably clear, straight, and round (Pl. VI). Hollow logs can be used, however, if the hollow is not too large and there is a thick rim of sound wood. A solid wood plug is driven into the ends of such logs, so that they can be turned in the veneer lathe. The logs are commonly cut into sections about 4 feet long and the usual thicknesses of veneer are from one-fourth to one-sixteenth of an inch. The cost of basswood veneer logs during the summer of 1920 was about $70 or $75 per 1,000 board feet, log scale, in the Lake States, the price depending largely on the quality and location of the timber. Some veneer plants buy woods-run logs and saw the lower grade, unsuitable for veneer manufacture, into lumber, which they are frequently able to utilize at the plant. Woods-run logs cost about $50 a thousand board feet in the summer of 1920.

Basswood is well liked for the manufacture of veneer because it cuts easily. Basswood logs can be sliced into veneer without boiling. In the spring and early summer the logs peel readily, so that no steaming is required. The veneer cores are usually sawed into lumber which some firms convert into cores for cabinet panels or which may be made into small articles such as bottoms and covers of small baskets and boxes.

Uses.—Basswood veneer is used as plywood where several plies are glued together; it makes a very high-grade, light-weight panel. It is

also used for drawer bottoms and mirror backing, because it is not inclined to warp excessively when used in this way. Thick veneer is used for core stock on which cabinet veneers are glued. Basswood veneer is used for the separators of storage batteries and for small cheese boxes.

TABLE 14.—*Consumption of basswood for excelsior, by States, 1911.*

State.	Cords.	State.	Cords.
Wisconsin	15,770	Michigan	1,590
Ohio	3,960	Virginia	60
Iowa	3,784	New Hampshire	25
New York	2,772	All other States	3,410
Pennsylvania	1,671		
		Total	33,042

EXCELSIOR.

Statistics on production.—Statistics of the Bureau of the Census on the production of excelsior are available only for the year 1911. Table 14 gives these statistics by States. The 33,000 cords of basswood consumed in that year in excelsior manufacture is equivalent to about 16,000,000 board feet of lumber. This was nearly one-fourth of the entire amount of wood reported for excelsior manufacture. Cottonwood and aspen grouped together and yellow pine were used in larger quantities, according to these statistics. When the different species are separated, however, aspen ranks first, basswood second, black cottonwood third, and the common cottonwood fourth.

Wisconsin is the main State in the manufacture of basswood excelsior; for 1911 nearly one-half of the entire amount used for this purpose in the United States was reported for that State. Mills making basswood excelsior are now located principally in northern Wisconsin.

Manufacture.—Excelsior is commonly termed "ribbon veneer," because it is composed of thin strands shaved from the surface of the wood. Requirements for excelsior are that it be elastic or resilient and light in weight and color. It is also preferred free from odor, although for some purposes, such as furniture packing, a slight odor is not objectionable. The quality most demanded is resiliency or "life"—that capacity of being compressed into a small volume and of expanding after being so compressed. Wood for the manufacture of excelsior should be light in weight, not brittle, soft, straight-grained and preferably free from odor. A light-colored wood is also desirable. Basswood meets the requirements of an excelsior wood better than any other timber and produces the best grades.

The scarcity and high price of the wood prevent its use in larger quantities. Excelsior manufacturers in regions where basswood

timber grows find it increasingly difficult to get supplies. Even in southern Wisconsin and Michigan there is little now obtainable, and firms in northern Wisconsin, which is probably the region in which the best supplies are located, find it necessary to use mainly other woods.

Wood for the making of excelsior is used in the form of the bolt, from which the excelsior is shaved by a special machine. The surface of the bolt is first scored by means of a series of steel teeth set the same distance apart as the width of the excelsior strand. The slicing knife then shaves off the excelsior in the finished form. Basswood bolts for making excelsior generally go into the machine 18 inches long, and the bolts are therefore purchased in lengths which are multiples of 18 inches with about an inch allowance for trimming the ends.

Basswood bolts are purchased either with the bark, or peeled, a somewhat higher price being paid for the peeled. In unpeeled bolts the wood is marketed in the green condition. The bark must be removed while the timber is green in order to peel thoroughly. Peeled basswood should be well seasoned before it goes into the machine. Manufacturers prefer not to buy excelsior wood which has air-seasoned for more than two years, however, because it may become brittle. Kiln-dried wood is apt to be brittle if it has been subjected to too high temperatures, and for this reason the air-seasoned wood is preferred.

Specifications for basswood for excelsior generally call for 37 and 55 inch lengths, either green and unpeeled or dry and peeled, the sticks to be sound, reasonably straight, and free from large knots. Sticks must be not less than 4 inches in diameter at the small end. Sizes up to 6 inches in diameter are left round; sizes from 7 to 12 inches are split in halves; pieces over 12 inches are split into four or more pieces.

The average yield of excelsior from a cord of basswood is about 1,600 or 1,700 pounds, depending on the dimensions of the bolts and the coarseness of the strands. This is below the average for all woods, which is about 2,000 pounds.

Waste.—The weight of a cord of air-dry basswood free of bark compared with the weight of its yield in excelsior shows a waste of approximately 30 per cent in manufacture. This waste results chiefly from squaring the bolts, trimming off knots and other defects, and from the loss of the small slab or "spalt" by which the dogs hold the bolt during the operation of slitting and slicing the excelsior. Even this small piece is often utilized by cutting it into paper-roll plugs, which go into the ends of rolls of wrapping and roofing papers.

Uses.—Excelsior is used largely for packing glass, earthenware, and other commodities for shipment. It is also used for mattresses,

the upholstery of furniture and vehicles, kennel and stable bedding, for decorative purposes in shop windows, stuffing dolls and toy animals, as a substitute for absorbent lint used in surgery, for filtration purposes, and to a limited extent for woven floor coverings. Basswood excelsior sells for the highest prices and serves mainly for the higher class of uses, such as the better grades of excelsior upholstery. Basswood makes a very good grade of wood wool, which is the name applied to excelsior composed of very fine strands, and in this form it is useful as absorbent lint and for packing fragile articles.

TABLE 15.—*Consumption of basswood for paper pulp for different years.*

Data.	1916	1917	1918	1919	1920
Average cost per cord f. o. b. mill	$9.57	$8.95	$13.81	$16.13	$18.39
	Cords.	*Cords.*	*Cords.*	*Cords.*	*Cords.*
Maine			1,017	734	1,594
New York	976	3,698	8,922	4,629	4,666
Pennsylvania	10,405	109	171		
All other States	100		2,000	4,436	4,209
Reduced by:					
Soda process	11,481	3,807	12,089	9,201	10,469
Mechanical process			21	479	
Sulphite process				119	
Total used	11,481	3,807	12,110	9,799	10,469

PULPWOOD.

Statistics on the use of basswood for paper pulp are available for the years 1916 to 1920, inclusive, and are given in Table 15. These figures show a wide fluctuation in the use of basswood, both by States and for different years. The amount of basswood converted into paper pulp is very small in comparison with both the total amount of wood used for pulpwood and the total annual consumption of basswood for all purposes.

Basswood is peeled free of bark before being sent to the pulp mill. It is converted into pulp almost entirely by the soda process and produces a high-grade product, principally book, magazine, and writing paper. It is well adapted for pulp manufacture, because of the softness and light color of the wood and its freedom from resin, which enable it to be bleached readily into high-grade stock.

SLACK COOPERAGE.

Basswood is well adapted for the heading of slack barrels, because it holds its shape well and is easily worked. Its light weight and light color also make it desirable for this purpose. Basswood is not suitable for barrels designed to hold heavy contents, such as castings and cement; it is used mainly for containers of food products. It is

preferred above all other woods for flour-barrel headings, because of its clean appearance. It makes a fairly tight barrel, because of its freedom from warping. Basswood is superior to yellow poplar for this purpose, because the latter wood is more liable to split. The best, or No. 1, heading for such barrels is usually of basswood. It is often used with cottonwood staves, and these two woods make a very clean and attractive-looking barrel.

Table 16 gives quantities and value of basswood heading produced in the years 1906 to 1911, inclusive, and in 1919, as reported by the Bureau of the Census, and in 1918 as reported by the Forest Service. There has been a large reduction in the amount of basswood used for heading in recent years, which can be ascribed to the scarcity and high price of the stumpage of this timber. Wisconsin, Michigan, and Minnesota have reported the largest quantities. Nearly all of that reported in 1919 was manufactured in Wisconsin and Minnesota. The production of basswood staves and hoops is also given in Table 16 for years in which it was reported for these purposes. Its use for staves and hoops in former years was due to its plentifulness rather than to its particular adaptability for these products, and in the industry it is now confined to heading alone. Cooperage manufacturers in the Lake States generally purchase the timber in the form of stumpage and in mixture with other species, such as beech, birch, and maple. Such timber in Minnesota has recently been purchased by cooperage firms for $8 or $9 per acre.

TABLE 16.—*Production of basswood slack-cooperage stock and value for different years.*

Year.	Heading.			Staves.			Hoops.	
	Number (thousand sets).	Value per 1,000 sets.	Rank.	Number (thousands).	Value per 1,000.	Rank.	Number (thousands).	Average value per 1,000.
1906	15,653	$47.11	4	8,307	$5.31	12		
1907	9,585	59.65	5	18,640	7.00	12		
1908	10,186	60.04	5	6,306	5.63	15		
1909	13,910	55.84	4	72,537	5.48	8	30	$7.00
1910	[1] 8,000	(2)						
1911	10,014	(2)						
1918	2,251	(2)	6					
1919	3,078	(2)	6					

[1] Approximate.
[2] Data not obtained.

TABLE 17.—*Annual consumption of basswood in the United States by secondary industries for different classes of uses.*

Industry.	Quantity used annually.	Industry.	Quantity used annually.
	Feet b. m.		*Feet b. m.*
Boxes and crates	86,979,611	Clocks	1,415,000
Planing-mill products, sash, doors, blinds, and general millwork	60,557,122	Machine construction	1,155,403
Woodenware, novelties, and dairymen's, poulterers', and apiarists' supplies	58,563,923	Ship and boat building	959,000
Furniture	33,146,276	Brushes	758,300
Trunks and valises	21,164,406	Shade and map rollers	702,500
Picture frames and molding	20,340,700	Pulleys and conveyors	625,000
Musical instruments	10,968,180	Printing material	352,600
Toys	8,739,242	Sporting and athletic goods	318,600
Agricultural implements	7,861,750	Sewing machines	310,000
Fixtures	7,114,755	Electrical machinery and apparatus	299,000
Vehicles and vehicle parts	6,418,308	Plumbers' woodwork	245,000
Matches	5,575,000	Dowels	167,500
Refrigerators and kitchen cabinets	5,221,634	Patterns and flasks	123,500
Car construction	5,148,521	Signs and supplies	100,000
Laundry appliances	4,980,670	Saddles and harness	52,000
Tobacco boxes	4,281,250	Gates and fencing	50,000
Boot and shoe findings	3,599,200	Weighing apparatus	35,000
Caskets and coffins	2,728,038	Dry kilns	35,000
Professional and scientific instruments	2,619,070	Whips, canes, and umbrella sticks	32,500
Handles	2,285,885	Elevators	10,000
Shuttles, spools, and bobbins	1,947,000	Tanks and silos	5,000
Chairs and chair stock	1,758,338	Artificial limbs	1,000
		Total	369,750,782

SECONDARY INDUSTRIES.

Statistics have been collected by the Forest Service covering the use of lumber by factories in the manufacture of various wooden products during the years 1909 to 1913. Figures on the annual consumption of basswood during this period are shown in Table 17 by classes of industries and in Table 18 by States. The quantities of basswood used for these different purposes are generally less at the present time than these statistics give. It is believed, however, that the figures show in a comparative way the importance of the different industries in the use of basswood, except as noted in the text. A detailed list of the reported uses of basswood by the industries is given in the Appendix.

TABLE 18.—*Annual consumption of basswood in the United States by secondary industries, by States.*

State.	Quantity used annually.	State.	Quantity used annually.
	Feet b. m.		*Feet b. m.*
Wisconsin	86, 100, 203	Connecticut	3, 559, 598
New York	56, 977, 220	Iowa	3, 237, 040
Michigan	56, 432, 782	New Hampshire	3, 096, 826
Illinois	50, 905, 500	Virginia	1, 591, 900
Minnesota	24, 278, 769	Missouri	1, 527, 587
Ohio	22, 833, 367	Rhode Island	909, 000
Pennsylvania	18, 698, 836	Delaware	707, 839
Indiana	12, 927, 003	District of Columbia	359, 050
Kentucky	6, 642, 000	North Carolina	265, 000
Tennessee	6, 028, 833	South Carolina	165, 000
Maine	4, 773, 100	Louisiana	160, 000
Massachusetts	4, 399, 000	Washington	107, 000
Vermont	4, 247, 630	Nebraska	103, 489
Maryland	4, 202, 050	All other States	317, 895
New Jersey	4, 056, 315		
West Virginia	3, 968, 450	Total	383, 578, 282

BOXES AND CRATES.

Woods suitable for the construction of boxes and crates are divided, on the basis of their physical and mechanical properties, into four groups. Basswood falls into the first group, including the lighter woods, which vary in average weights when thoroughly air-dry from 21 to 35 pounds per cubic foot, are soft and easily worked, hold nails moderately well, and do not readily split in nailing. Both softwoods (conifers) and hardwoods (broadleaf trees) are represented in this group.

Basswood is very desirable for certain kinds of boxes on account of its light weight, white color, and freedom from odor. Its good working qualities, freedom from excessive warping and splitting, as compared with other light-weight woods, and good nailing qualities also help to make it valuable box material. For boxes in which heavy merchandise must be shipped or which must stand much rough handling, such as boxes for export shipment, stronger and therefore heavier woods are demanded.

For boxes made to hold foodstuffs, such as crackers, chocolate, and candy, basswood is the ideal wood. In such boxes the contents are often in direct contact with the wood, and no odor or taste is imparted by basswood. Basswood is also used for shipping other kinds of provisions, such as dressed poultry and butter, because of its odorless quality. Boxes for this purpose are sometimes made from cheaper resinous woods and paraffined on the inside, but this process is expensive. Yellow poplar is used for such boxes, also cottonwood and tupelo. although the last two woods are much inclined to warp.

It is a common practice for manufacturers to make the shipping box serve as an advertisement for their products. Basswood makes an attractive box, and stenciling or printing shows to good advantage on the wood. White pine is the old reliable box wood, but it splits more readily than basswood. Boxes for holding bottles, particularly those containing soft drinks, are often made of basswood, because holes can be bored in the wood very close together in the same piece without splitting, and it holds its shape well even when alternately wet and dry.

Basswood has the disadvantage however, of discoloring, and of molding and decaying readily in damp situations, and this makes it unsatisfactory for many kinds of boxes. If left in contact with the ground, especially if the ground is wet, basswood will soon decay. For shipments which are likely to be subjected to considerable moisture, therefore, including bottled and canned goods, basswood is not altogether suitable.

Basswood is not used in as large quantities for boxes as several other woods, because of its comparative scarcity and high price. Of white pine and yellow pine, the main box woods, about one billion board feet each are used annually for boxes and crates, and the annual consumption of basswood for the same use is probably between 50 million and 100 million board feet. Yellow poplar, cottonwood, and several other woods are used in larger quantities for boxes than basswood, because the supply of the latter wood is much less and the price generally higher. It is not usually made into large packing boxes, but its use is largely confined to small, special boxes where the desirable qualities of the wood can be made to serve to best advantage. In basswood, the lower grades, which in other species make up the bulk of the box material, are unfortunately not suited to the manufacture of some of the main kinds of boxes for which it is valued, because of defects, such as dark and decayed streaks, which are usually present in the low-grade stock. Box makers, therefore, generally prefer to use other woods, such as yellow poplar, cottonwood, aspen, sap gum, and tupelo.

Box factories prefer the No. 1 common lumber grade. On account of the high price, however, they generally use No. 2, and even No. 3 common. Usual thicknesses of basswood lumber for boxes are three-eighths, one-half, and thirteen-sixteenths of an inch. Narrow widths can often be utilized. Up to a few years ago, factories in Ohio, Indiana, and Illinois obtained the greater part of their basswood from Wisconsin and Michigan. These factories now depend for the most part on West Virginia for this timber. On account of the more limited supplies of this wood and greatly increased freight costs, the use of basswood in this section is being greatly curtailed. Even box factories of Michigan and Wisconsin now find it difficult

to get sufficient quantities. Recently box manufacturers in the Lake States have been using aspen, commonly called "popple," in place of basswood. The aspen must be used in narrow widths.

Box makers use the grading rules of the various lumber associations in the purchase of lumber. For box shooks, however, grading rules have been drawn up for different woods by the National Association of Box Manufacturers. There are four grades for basswood shooks—clear, No. 1, No. 2, and No. 3, as follows:

Clear grade.—Lumber in the clear grade of boxes must be practically free from knots, and must be of good color, running largely to white basswood. This grade may contain, however, 15 to 20 per cent of red color, but must not contain black or brown.

Grade No. 1.—Lumber in grade No. 1 of boxes must be good, sound material of mixed colors, light and brown, and should contain at least 50 per cent of reasonably light-colored basswood. Small, sound knots are allowed in this grade, and some stain.

Grade No. 2.—Lumber in grade No. 2 of boxes must be reasonably strong but shall not be graded as to color. Brown basswood can prevail in this grade; small knots and shake can prevail, but not in sufficient quantities to materially weaken pieces. Some stain is allowed in this grade.

Grade No. 3.—Lumber in grade No. 3 of boxes is not graded as to color. Black knots and stain are allowed in this grade.

Michigan, Wisconsin, Illinois, New York, and Minnesota use basswood in largest amounts for box manufacture.

Baskets, mainly those for holding grapes and berries, are often made of basswood. The splints are sometimes of this wood because of its good working qualities and good appearance; more often, however, the sides are of some tougher wood, as birch or maple. The covers and bottoms of such baskets are quite commonly of basswood, because it is light in weight and nails easily. These parts, since they are small, can often be made from waste in the manufacture of other basswood articles. Low-grade basswood is often used for crates. It is well suited for light crating, and narrow-width material can be used very advantageously for this purpose.

PLANING MILL PRODUCTS, SASH, DOORS, BLINDS, AND GENERAL MILLWORK.

Basswood has been a favorite wood for many years for planing mill products, sash, doors, blinds, and general millwork, particularly for inside finish, becasue it machines to a smooth surface when seasoned, keeps its shape well, and takes finishes extremely well. It is one of the best woods for enamel work because of its uniform, clear, light color, smooth finish, and even texture, which absorbs and holds the paint evenly and well. It also finishes well with other paints and varnish. There is a greater demand for figured wood for these products, such as that of red gum, birch, and oak. Much

basswood is used, however, for interior woodwork, especially for ceiling and in the form of wide boards for finishing and panel work. On account of its adaptability to cutting with tools, basswood serves well for moldings and carved work in interior finish of various kinds. Much basswood is also manufactured into bevel siding, but it is not so well adapted to exterior work because of its liability to decay.

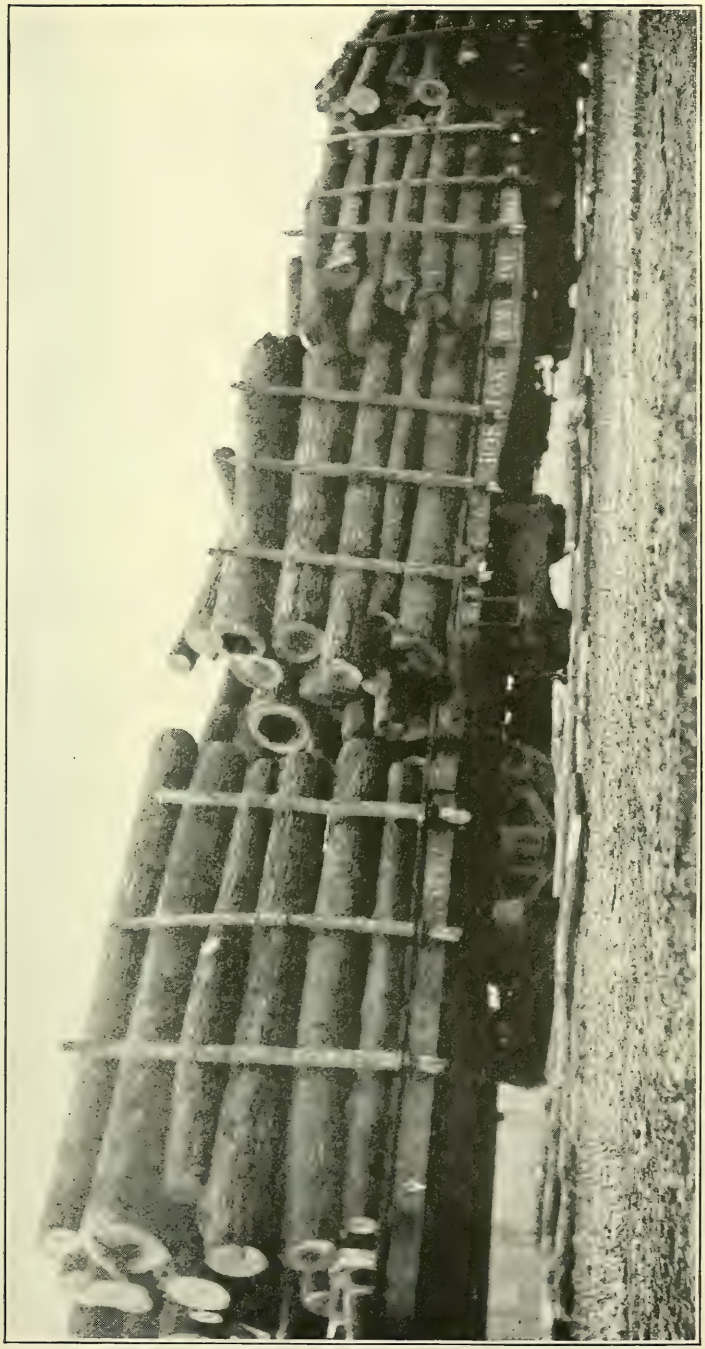
Michigan and New York lead in the manufacture of this class of products from basswood. Formerly much basswood was used for this purpose in Ohio, but increasing scarcity and cost of shipment have greatly reduced the quantities going into the industry. Rising costs of the upper clear grades have had much to do with discouraging its use, for the dark-colored and streaked material of the lower grades is much less valuable for these purposes. Yellow poplar, birch, and the softer grades of pine are now generally used in place of basswood.

WOODENWARE AND NOVELTIES.

Basswood is made into articles of woodenware used in the shipment of provisions, such as pails and tubs. It is well liked for such uses, because it is light in weight and odorless, and the light color of the wood makes a good appearance. On account of its good working qualities, it is easy to manufacture into such products. It also has the advantage of showing stenciling extremely well. The light weight of the wood effects a large saving in freight, both when shipped empty to the purchaser and when filled with provisions.

Basswood is the favorite wood for candy pails, because it gives an appearance of cleanliness. For the same reason it is used for jelly pails, called "jelly kits," which are used for the shipment of jelly in bulk. Most liquids will seep through basswood, but jelly hardens in the wood and prevents the liquid from coming through. Fish pails and pickle pails are sometimes made of basswood, in which case they must be paraffined to make them water-tight. Such pails are made more commonly of a hard pine. Lard pails, lard tubs, and grease pails are commonly made of basswood. They are usually varnished on the outside and given a finish to resemble the grain of oak or some other hardwood. Candy pails are sometimes grained in this way also. Fish, pickle, and jelly pails are usually painted or decorated in some characteristic manner.

Generally only the sides and covers of these pails are of basswood. The bottoms are usually made of Norway pine, maple, or birch. A fairly hard wood is necessary for the bottoms in order to bear the weight of the contents of the pail and to make a tight, rigid joint. The staves for the sides of these pails are cut from basswood bolts by a tight-stave circular saw. After being thoroughly dried they are trimmed to the proper length and width and a small tongue and groove made along the edge on the two sides (fig. 5). They are



WOODS-RUN BASSWOOD LOGS PURCHASED BY A WOODENWARE FACTORY FOR MANUFACTURE INTO CANDY PAILS.

TOP OF 17-INCH DIAMETER BASSWOOD LOG WITH A 4-INCH RIM OF SOUND WOOD. HOLLOW LOGS WITH A SHELL OF SOUND WOOD AS NARROW AS 4 INCHES ARE ACCEPTED BY SOME FACTORIES.

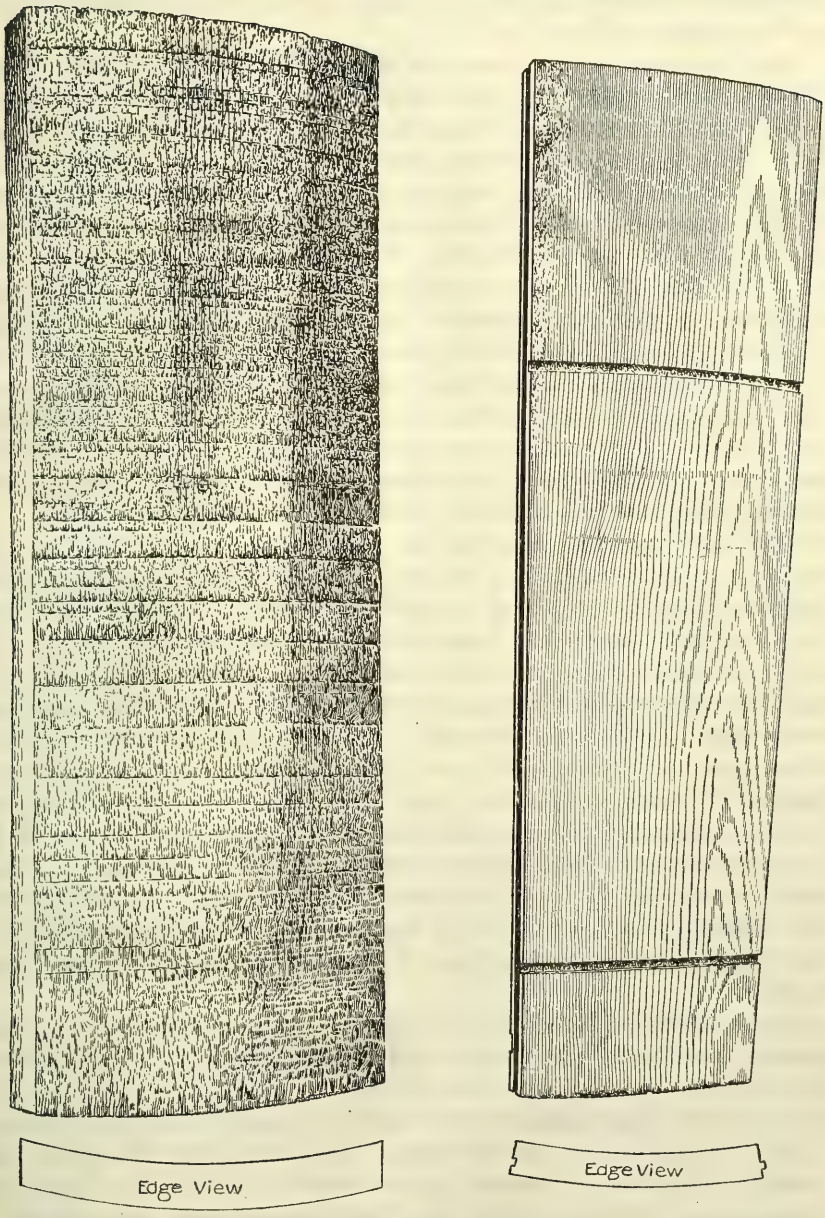


FIG. 5.—Rough and finished candy pail staves.

then assembled to form the partly finished pail, which is grooved inside to receive the bottom and outside for the wire bands. This is next turned smooth and sanded inside and out, the bottom inserted, and the bands put on.

Dark basswood can be used for these pails as well as light. The wood must be quite clear, but small, tight knots are not objectionable. The timber usually comes to the factory in the form of logs. Some firms buy only No. 2 logs, which is the grade below the veneer-log grade, since they can use sizes as small as 6 inches in diameter at the small end. They prefer woods-run logs, however, if these are not too high-priced (Pl. VII). The pail covers are generally made from the waste in manufacturing staves. Hollow logs, which are quite characteristic of basswood, can be utilized to good advantage, because the outer sound rim of wood, if not too narrow, can be cut into stave bolts and staves with comparatively little waste. Such logs can usually be worked much more profitably into staves than into lumber. Some hollow logs otherwise sound will yield one-third more than the log scale in pail staves, when for lumber there would be little if any overrun and only narrow widths could be obtained.

Logs are generally purchased in 8 to 10 foot lengths, but much material is also purchased in lengths of about 3 feet, especially small-diameter timber, which is bought of farmers. Hollow logs are accepted, but they should have at least a 6-inch rim of sound wood. Hollow logs are sometimes taken down to a 4-inch shell, but such material often can not be handled at a profit because of the expense of the labor to work it up (Pl. VIII). Small logs are profitable because there is a large overrun in such logs compared with the yield in lumber. Although factories prefer the timber not smaller than 6 inches in diameter, 5-inch and even some 4-inch sizes are taken if of good quality. Some manufacturers prefer to purchase by the cord of 128 cubic feet and in 39 and 52-inch lengths. On account of the difficulty of getting it cut up, much small material is now shipped in 12-foot lenths. Second-growth timber is considered the best quality.

Prices paid for basswood are quite variable, depending on the general quality of the timber and the location; they range from about $20 to $30 a thousand board feet f. o. b. cars at loading point. Freight costs often amount to $5 to $10 a thousand in addition to this.

Pail manufacturers of Michigan, Wisconsin, and Minnesota in some instances own extensive timber tracts in the northern parts of these States from which they get a large part of their raw material. Basswood is becoming scarce even in this region, and manufacturers must depend on other species. Aspen is being used to some extent in place of basswood, although the supply is limited, sizes are small, and the wood is much inclined to be defective, doty, and discolored.

The wood of balm of Gilead, a tree which resembles the aspen, is not liked because it is shaky and otherwise defective. The white or paper birch is sometimes used when supplies are available and is said to make a good pail. Second-growth white pine, if not too defective, is also fairly satisfactory.

Factories in Michigan, Wisconsin, and Minnesota have difficulty in getting sufficient suitable timber, and those which are not located conveniently to a supply from the northern parts of these States have in some cases been compelled to go out of business or move farther north. Even this supply is becoming so scarce that large manufacturers realize that they must look to new territory. It is probable that a large part of the industry will be transferred in the near future to the Pacific coast, where, in some instances, tracts of softwood timber have been already acquired for the purpose.

A large demand exists for pails of the kind just described. As a rule, they are not used a second time, on account of the cost of shipment and because they find a ready sale at retail stores.

The cheese box is another common woodenware commodity made of basswood. Small cheese boxes used for shipping fancy cheeses are commonly made of basswood throughout. Veneer is used for the sides, and small pieces of thicker stock for the bottoms and covers. Basswood is also sometimes used for the heading for large cheese boxes; for the sides of these larger boxes a strong tough wood, such as elm, is required. In making the small cheese boxes the better grade of logs is used for the veneer, and low-grade and small logs are sawed into lumber for the bottoms and tops. Such lumber, even though defective, yields a large amount of the small, clear pieces required. Basswood is easy to manufacture into this product and makes a light and attractive box for the purpose.

A very large number of other articles of woodenware are commonly made of basswood. Important among these are kitchen utensils, such as bread boards and boards for cutting slaw and other vegetables; also such articles as bowls and candlesticks, which are turned on the lathe and to which hand carving may be added. Cloth boards on which goods are wound, lap boards, and cutting boards of various kinds are commonly of basswood, because it is white, light in weight, and not so readily split as many other light woods. Small, clear pieces of waste basswood are often worked into such articles as fan handles. Wooden novelties of many kinds, often sold as souvenirs, are made of basswood because of its good working qualities. Checkers and dominoes are commonly of this wood, because it shows painting to excellent advantage. Basswood is the favorite wood for pyrography because of its whiteness, although little is now used in this way. Porch shades, snow shovels, and ladders are other articles in which basswood is valued because of its light weight. Because it

shows printing and writing well, it is made into barbers' checks, and labels attached to hay bales on which the weight is written.

Since plentiful supplies of comparatively cheap timber are necessary in the manufacture of different kinds of woodenware, the factories are located near the principal supplies of the timber they use. Wisconsin consumes by far the largest quantities of basswood for these products, and Michigan and Minnesota also use large amounts. New York and Ohio are likewise important in the consumption of basswood for woodenware articles. Outside of these five States the amount of basswood used for these purposes is very small.

APIARISTS', POULTERERS', AND DAIRYMEN'S SUPPLIES.

Because it gives a white, clean appearance and is odorless, basswood is the preferred wood for the honey section, which holds the honeycomb in the hive, and in which comb honey is retailed to the trade (fig. 6). Purchasers are very discriminating concerning the appearance of the package holding honey. A dark or discolored wood gives the impression that the honey is inferior in quality. Only the white, clear basswood will serve for the best grade of honey sections. A second grade is usually made which is cream-colored. This grade must be uniformly colored, however, and the wood must be free from defects. Although the best grade of basswood lumber is most suitable for the manufacture of these sections, factories find it more economical, on account of the high price of such stock, to purchase a lower grade or a mixed grade and to work up brown and otherwise discolored stock, which is unsuitable for honey sections, into fences and separators which go between the honey sections in the hive (fig. 6). These parts can be satisfactorily made of other woods, such as pine, when sufficient basswood is not available. It is stated that pine is even more suitable, because the basswood is liable to mold. Some firms purchase basswood lumber of the grade No. 1 common white, in which a small percentage of brown wood is admitted, and which costs them about $10 a thousand board feet more than the regular No. 1 common grade. A combination of No. 2 common and better grades, called "log-run," can often be used to good advantage by such factories, since a large percentage of clear, white stock can often be worked out. Narrow-width and short-length lumber can be utilized; and round-edge, i. e., lumber which has not been edged, can be worked up advantageously.

Several machine operations are necessary in making the honey section. First, the plain strip is made by resawing inch boards; the sides are next trimmed out, which allows the bees to enter when the sections are placed face to face; the strips are then notched at each end to make a lock-cornered joint; finally, three V-shaped scorings are made across each piece where it is later bent at right

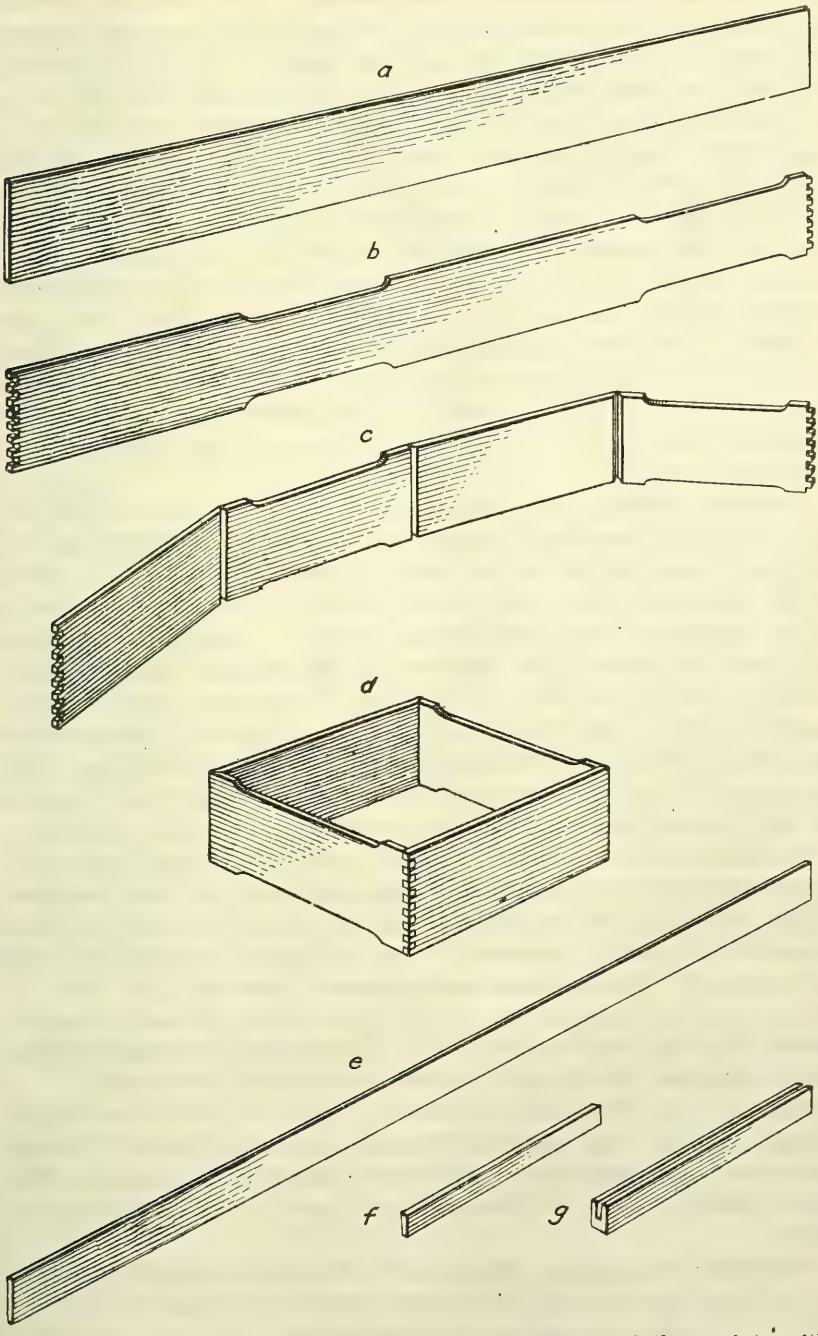


FIG. 6.—Apiarists' supplies made of basswood: *a*, *b*, *c*, and *d*—the different steps in the manufacture of the honey section,; *e*, *f*, and *g*—parts making up the "fences" or separators that go between the honey sections in the hive.

angles to form the completed honey section. The strips are shipped flat from the factory and should be steamed at the scorings to bend satisfactorily. Apparatus is sold to apiarists for this purpose, although the strips can be bent without breaking by moistening the wood where the scorings have been made. Basswood does not break readily when bent in this way, which makes it valuable for this use.

Manufacturers of honey sections prefer to get their basswood from the Lake States. Some is purchased from West Virginia mills, but this is not considered so white and clear or so suitable for this use. Basswood which is cut in the winter is preferred for the manufacture of honey sections, because it is less likely to discolor than if cut in the summer. Some firms make a practice of buying it partially seasoned in the winter. It is then piled in the open on sticks for 9 months to a year, after which it is piled solid for a year under cover. Where this practice is followed it is necessary to keep a very large stock of lumber on hand.

Factories making honey sections and other bee-keepers' supplies generally find it necessary to manufacture a number of miscellaneous articles in order to utilize their small-dimension and defective basswood. Such articles as small boxes, handles of cheap fans, calendar sticks, and washboards are among the most common. Trimmings cut from the ends of thin basswood strips are sold for hay-balers' labels, on which weights are written. Brown and dark-streaked material can be used for these purposes. Basswood is sometimes used for the interior of hives and occasionally for the sides, but white or western yellow pine is more often used for these parts, and cypress for the tops and bottoms, because a more durable wood is desired.

Manufacturers of apiarists' supplies assert that there is no satisfactory substitute for basswood in the manufacture of honey sections. Yellow poplar is not so strong at the corners of the honey sections where it is bent and, moreover, it not in general so white and clear as basswood. The sapwood might serve, however, if it could be obtained in large quantities. Cottonwood might be made to serve, but it does not machine smoothly. The warping of tupelo, which might otherwise be suitable, precludes its use for the purpose.

Other articles for which basswood is adapted are butter molds, because it looks clean and can be easily carved, and parts of churns, on account of its light color. Incubators and poultry coops are often made partly of basswood, because it is light in weight and easy to work.

New York, Wisconsin, Illinois, and Ohio use the largest quantities of basswood for this line of wooden products, because of the bee, dairy, and poultry industries in those States.

FURNITURE.

Basswood is an important furniture wood because it glues well and takes and holds screws and nails very satisfactorily. It is well liked for such parts as drawer sides and bottoms, mirror backing, and shelves, because it does not warp to any great extent. Basswood is often used for the inside and hidden parts of expensive furniture. It is not generally used for outside work in furniture, because it lacks the strength of other woods, such as oak and red gum, and does not have an attractive grain or figure for finishing in the natural state. It is, however, used in enamel work, for which purpose it is well adapted, because it has a uniform texture, takes paint well, and, since it does not shrink and swell to any great extent, it is not inclined to crack the enamel coating as many other woods do.

Basswood serves well for cores of panels finished in expensive veneers. It is especially well suited for producing curved surfaces in furniture, because it can be readily bent into various forms by steaming, holds its shape after it is dry, and glues well. It is in demand, therefore, as a core wood for curved and irregular surfaces which are to be covered with figured veneer. Basswood is valuable also as core stock for large panels, because it can be obtained in large, clear pieces. Experiments on panels show that there is less warping when a low-density core wood, such as basswood, is used than with a high-density core wood. The low-density core wood has the additional advantage of making a light-weight panel. Basswood, also, does not split so readily as many other light-weight woods and holds the veneer well. In the gluing process basswood absorbs the glue very readily; therefore, a liberal amount of glue should be used in order to avoid a starved joint.

The following States use basswood for furniture in largest amounts: Illinois, New York, Michigan, Pennsylvania, Wisconsin, Minnesota, Ohio, and Indiana.

TRUNKS AND VALISES.

Basswood is an ideal wood for trunks because it is light in weight, does not split readily, holds nails well, is easily worked, keeps its shape well, and is available in wide, clear pieces. Some trunk manufacturers use basswood exclusively for the trunk box and also for the lid and trays. The trunk box may be made up of a single thickness of basswood or the sides may be 3 or 5 ply. Trunks made of plywood are more serviceable, because the plywood panels will stand shock better without splitting or breaking than the solid panels. The plywood is made of three or five thicknesses of basswood veneer one-sixteenth to one-twelfth of an inch thick, glued together with the direction of the grain in each sheet at right angles to that in adjacent sheets. Each ply may be made up of several strips of veneer, and small

defects are permitted if they do not interfere with the soundness of the stock. Discolored material can therefore be used. The trunk-box is nailed together and the nails are placed very closely. Even the thin pieces making up the trunk tray are usually fastened together by nailing. The trunk box is covered by an outer and an inner layer of fiber glued to the plywood, which protects the wood and adds to the appearance of the trunk. When the trunk is made of one thickness of wood throughout, boards, generally three-eighths or seven-sixteenths of an inch in thickness, are matched by means of tongue-and-groove along the sides.

Sample cases are often constructed like trunks and made of basswood. White pine is said to make a fairly satisfactorily trunk box, but splits more readily than basswood. It is said that yellow poplar makes too heavy a box, and cottonwood is hard to work and does not hold its shape well. Factories making the solid boxes usually purchase inch lumber and resaw it. They may buy low-grade lumber and cut out the suitable stock, or, they may find it advantageous to purchase log run and utilize the various grades. Makers of plywood trunks generally buy the sheets of plywood already glued up. Veneer plants making plywood for trunks use fairly clear logs 10 inches and up in diameter, which they cut into lengths of about 4 feet. The cores left after cutting the veneer can be profitably used by such factories for making high-grade cabinet panels, since basswood is an excellent core wood for such panels.

Wisconsin and Ohio use the largest quantities of basswood in the manufacture of trunks, followed by New York, Illinois, Michigan, and Pennsylvania.

It is not likely that basswood will be replaced by other woods in trunk manufacture until its extreme scarcity makes this necessary. Large quantities of southern pine, usually the softer grades, are used for low-priced trunks. To some extent, trunk makers are using red-gum plywood, which they are able to make thinner than the basswood because of its greater strength. By making it into plywood the natural warping of red gum is very largely overcome.

PICTURE FRAMES AND MOLDING.

Basswood was formerly the principal wood used for picture frames and molding, because it works well with tools, finishes well, holds its shape, and is well adapted for the highly decorative composition and gilt work which was very much in demand until recently. However, the demand is now very largely for embossed work. In embossing, the tool, which is usually a heavy metal disc, is forced into the wood while hot and leaves an imprint. Basswood exhibits a certain amount of sponginess under this treatment, the wood rising where the imprint is made, so that it is not satisfactory for the purpose. For this

reason much smaller quantities are now used in this industry than formerly. Red gum has been very largely substituted in embossed work. Basswood is still used to a large extent for plain moldings which are to be painted, and also as core material for moldings finished in highly figured veneers. It is said to be the most satisfactory core material available for this use. It is also well liked for carved moldings, because it cuts so well with tools. Illinois and New York were the principal States reporting basswood for these products.

MUSICAL INSTRUMENTS.

Basswood enters very largely into the manufacture of musical instruments, chiefly pianos and organs. It is used mainly for interior small parts, for which its light weight and ability to hold its shape make it suitable. It is also much used for piano and organ cases. For organ bellows, wind chests, and swell boxes it is especially suited, because of its lightness, good working qualities, and freedom from warping. Basswood is the choice wood for piano and organ keys because of its whiteness, light weight, and good staying qualities. Only the highest grade of the wood, however, serves as piano-key stock. This is selected white wood which is seasoned with much care, since a small amount of warping in the key may interfere with its action.

Basswood also goes into the construction of phonograph cabinets, in the form of cores for the panels finished in mahogany, walnut, and oak veneers. Stock of small dimensions can often be utilized in this way.

Basswood is employed for necks of mandolins, for violin cases, and for other such uses. The principal States using basswood for musical instruments are New York, Illinois, Connecticut, Michigan, and Ohio.

The highest average cost reported for basswood by the industry indicates that a high grade of stock was purchased for this class of uses. This average cost was more than double that reported by the box-and-crate and woodenware industries for basswood, and nearly 50 per cent more than that reported for furniture.

TOYS.

Basswood is highly valued by toy makers because of its good working, staying, and finishing qualities, on account of which it is the principal wood used in the United States, both for toys made entirely of wood and for the wooden parts of metal toys. It is not only used in greater quantities, but enters into the manufacture of more kinds of toys than any other species. Among the most common toys are wagons and buggies, in which basswood is used for the bottoms. Other toys in the same class which use much basswood are sleds, automobiles, and wheelbarrows. Hobbyhorses and small toy ani-

mals of various kinds are other products made largely of this wood, as well as toy boats. Toy pianos and doll houses are usually of basswood, which is also the favorite wood for toy cannon and popgun stocks because it is easily bored and turned to shape. It is the wood used in making the wooden doll of recent introduction and valued for its indestructibility. The head, which is also of solid wood, is carved to form the face and enameled in lifelike colors. Basswood is very largely employed in the making of toy blocks of various kinds, because it is so easily worked and takes printing well.

Toy manufacturers generally purchase a combination of No. 2 common and better grades from which they cut the pieces of different sizes and quality for their needs. They use much thin lumber, such as for the box boards of toy wagons and wheelbarrows, and they are able to utilize the material very closely, even though considerable clear stock is required, because of the very large variety of products manufactured. Some firms use the waste from the manufacture of other articles, such as piano and organ keys. However, since toys must ordinarily be produced at low cost, the general run of small and odd-sized pieces of waste from other factories can not usually be employed at a profit, because of the added expense of labor in working it up. Toys are generally manufactured in large quantities by machinery, and the production would be seriously reduced by the use of much small material of various shapes. Some firms using basswood for other articles utilize their own waste by converting it into such toys as can be made to advantage from the sizes they have available, and this can often be done at a considerable profit.

Yellow poplar is also used in toy manufacture, but where it is to be left unpainted the color is considered not so attractive as that of basswood. White pine is also put to the same use but it is not so desirable, because it splits more readily. On account of its limited supply and the advancing prices on basswood and its most common substitutes, toy manufacturers are constantly seeking a suitable new substitute. Cottonwood is not satisfactory, it is stated, because it does not machine to a sufficiently smooth surface. By careful seasoning it is possible that tupelo and the sapwood of the red gum can be utilized, at least for those toys which are intended for indoor use. The principal States making products of this class from basswood are New York, Pennsylvania, Ohio, and Wisconsin.

AGRICULTURAL IMPLEMENTS.

Basswood enters into the construction of a large variety of agricultural implements. It is used mainly for inside work, chutes, drawers, partitions, and boxes of various kinds, and in general where a high degree of strength is not required. It is a favorite wood for use in grain separators, seeders, and fanning mills, for

parts of feed mills, and in containers or conveyors of shellers, graders, and planters. It also serves in a small way for parts of such farm implements as cultivators and hayrakes.

Wisconsin and New York use the largest quantities of basswood for these products. Where basswood is not so readily available, other woods are used for the same purposes. In fact, yellow poplar is used in much larger quantities in this industry, is fully as suitable, and has the advantage of being available in larger quantities and greater widths. Southern yellow pine and white pine are also much used for these purposes.

FIXTURES.

Basswood is an important wood in the manufacture of store, office, and bank fixtures and is also used for church and school furniture, such as pews, altars, and desks. It goes mainly into the interior and hidden parts, where it is used principally in the form of small pieces. It is valued for such parts because it is a good wood to work with tools and takes nails and screws well. It also serves for the cores of high-grade panels covered with veneer of figured wood. In this class of products, as in furniture, much of it is used for drawers, linings, and partitions, and it is well adapted for cases and racks for holding and displaying goods in stores as well as for medicine cabinets and cupboards in dwellings.

Minnesota, Wisconsin, Michigan, and Illinois use the largest quantities of basswood for fixtures, because of its availability in those States. Prices paid for basswood for fixtures average about the same as for furniture, showing that about the same grade of stock is used for the two purposes.

VEHICLES.

The chief use of basswood in vehicle construction is for the bodies and panels of carriages, wagons, and automobiles. Much less wood than formerly is now used for vehicle body panels, because the wooden panel of the automobile body is now practically superseded by steel. Basswood is often used for wagon-top slats, and it also frequently goes into the construction of sleigh bodies, for which it is well adapted. Baby-carriage bodies and wheelbarrow sides are other vehicle parts for which the wood is suitable. It is used also for storage batteries, on account of its ability to hold its shape.

Wisconsin and New York are the principal States in the consumption of basswood for these purposes.

MATCHES.

A satisfactory match wood must light easily and burn with a good flame, and the stub should not retain the live coal long after the blaze has expired. It should be straight-grained and easily worked,

and should also hold the dipping material well. The wood should be practically free from defects and preferably light in color. White pine is the principal match wood in the United States, from which the round match is made by cutting from clear blocks of wood. Basswood is second in importance and is used in much smaller quantities for the production of the square or veneer match.

For the manufacture of the veneer match raw material is received at the factory in log form. The logs are boiled and cut into veneer the thickness of the match on a rotary veneer lathe. The veneer is then cut into strips in width corresponding to the length of the match stick. The sticks are then split from the veneer, and after they are thoroughly dried the ignition end is paraffined to make them burn better and is headed with the ignition material.

Aspen is the wood which is used almost exclusively in Europe for manufacturing veneer matches, and basswood has similar properties. Basswood matches are not so attractive looking as those made from white pine, because the basswood does not split so straight, and the match sticks are often very imperfect (fig. 7). Otherwise basswood is a very satisfactory wood for matches. Match factories use only No. 1 or veneer logs 8 inches and over in diameter. They are generally purchased in lengths which are multiples of 22 inches if less than a foot in diameter. Larger logs are usually any length from 3½ to 14 feet. The cost of such logs at the factory ranges from about $50 to $55 a thousand board feet. The timber used for this purpose is obtained mostly from farmers' woodlots, since the larger and more desirable timber goes mainly into the manufacture of lumber and high-grade veneer. This small sized timber is frequently defective, with many small knots, and there is much waste in converting it into the clear veneer stock. The logs are utilized very closely and can be cut down to a core as small as 2½ inches.

Farm woodlots in Iowa, Minnesota, and Wisconsin furnish a large part of the basswood used for matches.

REFRIGERATORS AND KITCHEN CABINETS.

The class of products included under refrigerators and kitchen cabinets might be termed kitchen furniture, since it includes refrigerators, kitchen cabinets, kitchen tables, and, in fact, all kinds of furniture made for kitchen and pantry use, except kitchen chairs. Basswood is well liked for these articles, because it has a clean appearance in the unfinished state and is odorless. It can also be painted or varnished advantageously, if desired. It is much used for the lining, shelves, drawers, and compartments of kitchen cabinets and for the tops of kitchen tables. Such parts are usually kept clean by scrubbing with soap and water, and basswood keeps its

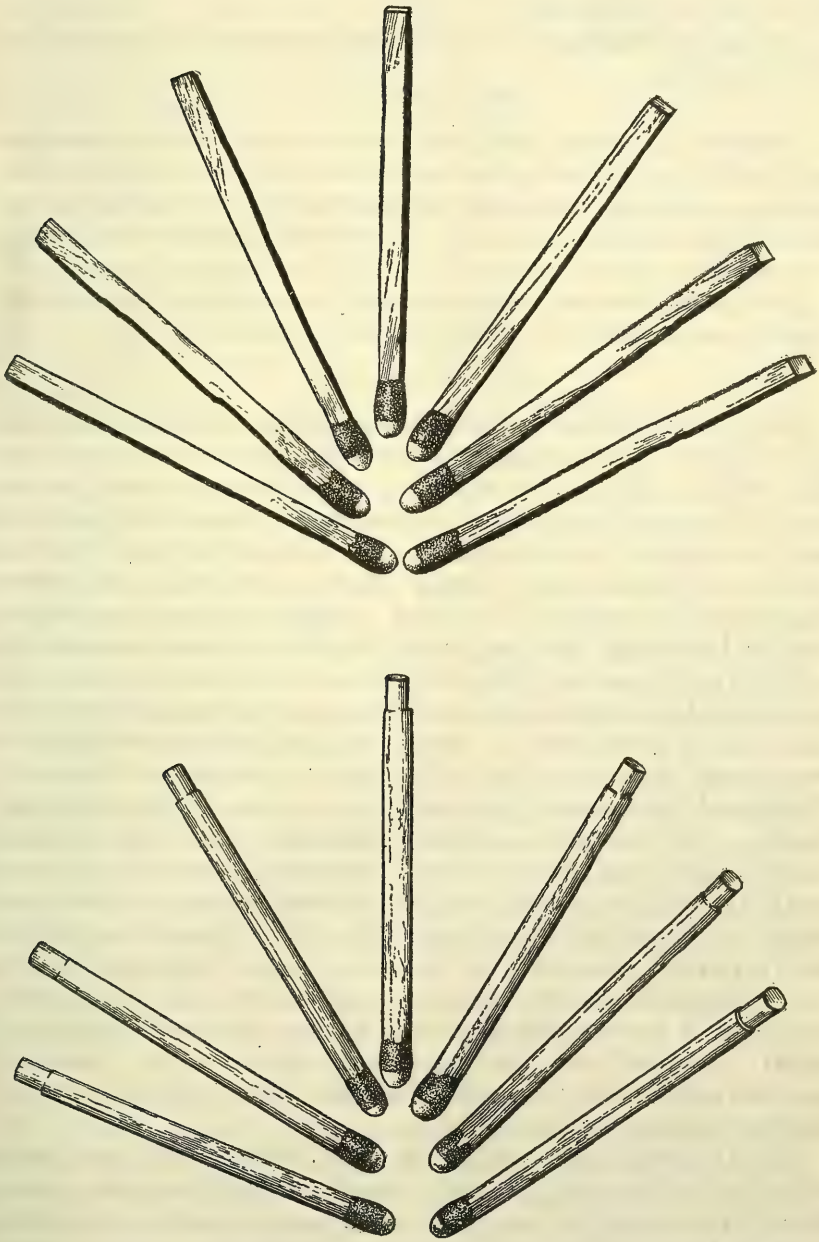


FIG. 7.—At top, basswood matches made by veneer process; at bottom, standard white pine matches.

shape when treated in this way. The No. 1 common grade or log run is generally used for the manufacture of such articles from which clear stock is cut for exterior parts, and lower-grade stock is utilized for the interior woodwork.

Indiana and Michigan use the largest quantities of basswood for these purposes.

CAR CONSTRUCTION.

Basswood is used in a small way in the construction of locomotives and freight cars in places where much strength is not required. For passenger cars, both steam and electric, it serves for exterior and interior finish, including panel work. It is valued highly for cores finished in expensive veneers, such as are seen in Pullman and private cars.

The use of basswood in this industry was reported, generally in rather small amounts, by a large number of States.

LAUNDRY APPLIANCES.

Basswood is the favorite wood for the manufacture of a large number of articles grouped under this head, because of its whiteness and light weight. For ironing boards it is the preferred wood, on account of its good appearance unfinished, and because it works so easily to a smooth surface and does not warp or split readily in use. Besides the regular-sized ironing boards, small skirt and sleeve boards are also made of this wood. Adjustable curtain stretchers used in laundering lace and other thin-fabric window curtains are preferably of basswood. The clothes rack which folds together like a screen and is used in drying clothes is commonly made of this wood. Basswood is much used for the front panel and top crosspiece of washboards, because of the white, clean appearance of the wood. Washboards are generally purchased on the basis of their good appearance, and one with a white, clean-looking panel will sell more readily than a less attractive one. Moreover, a printed advertisement is usually put on the panel by the manufacturer, and basswood shows such printing exceedingly well. Other laundry appliances are frequently stenciled with the name of the firm, and for this reason basswood is the favorite wood. Clothespins of the kind composed of two wooden strips held together by a wire spring and called "clip pins" are sometimes made of this wood. Basswood also serves for parts of washing machines where good strength and wearing qualities are not requisites.

Manufacturers using mainly the clear, white wood have much difficulty in disposing of their discolored and low-grade stock. Some firms covert this stock into small articles, such as round bottoms of fancy baskets; others sell such material to box factories. Manufacturers generally find it most advantageous to buy log-run lumber and work out of it the stock they need, rather than to pay

the price for very high-grade lumber. Some firms using large quantities of basswood for other purposes find it advantageous to utilize small clear pieces in the manufacture of small laundry articles, such as washboards. Basswood has been so high-priced and difficult to obtain in recent years that many manufacturers of laundry appliances have been compelled to substitute yellow poplar, although its color is not generally liked so well, and much of it is more difficult to work.

The largest quantities of basswood used for these products have been reported from Illinois, Michigan, New York, and Pennsylvania.

TOBACCO BOXES.

Because of the difficulty of obtaining Spanish cedar, which is the standard cigar-box wood, a large number of substitutes are employed. A satisfactory wood for cigar boxes should work well into thin lumber or veneer, hold its shape, nail without splitting, and have an attractive appearance. Basswood, stained to resemble Spanish cedar, is probably the best substitute. The imitation is made even more complete by passing the thin lumber between rollers which stamp it to give the appearance of the genuine cedar, and the cedar odor may be imparted by washing it with extract of cedar shavings and sawdust. Only the highest grade of lumber is used for this purpose. It is carefully piled on sticks and kiln-dried just before it is resawed into thin cigar-box lumber, which is usually about three-sixteenths of an inch in thickness. Basswood is also used as core, on which thin veneer of Spanish cedar is glued, and is well adapted for this purpose.

Some basswood goes into the construction of tobacco boxes of other kinds, because it does not impart stain or odor to substances in contact with it. It is also used for humidors, which prevent cigars from drying out. Yellow poplar is also used for these purposes. Tupelo and red gum are likewise employed for these uses; but they are less desirable, because of the darker color of the woods and their tendency to warp.

The greater part of the basswood reported for the manufacture of cigar boxes was used in Wisconsin factories.

BOOT AND SHOE FINDINGS.

The principal use of basswood in boot and shoe findings is for shoe forms or fillers. These are similar in shape to the last, which is of some hardwood, usually hard maple. Shoe forms are used to maintain the natural shape of the shoe in samples displayed in show cases and when being handled by traveling salesmen. They are made to fit the shoe perfectly and give an effect similar to that produced when the shoe is on the foot. Fillers should be light in

weight to save cost in transportation in salesmen's trunks. These forms are tooled to final shape from the rough-turned blocks; and to reduce weight to the minimum they are often hollowed. Basswood is considered the most practical wood for this use, because it is light in weight, easily worked, does not split readily, and holds its shape well. The wood is also used for lasts for rubber boots in some instances. The increasing high cost and scarcity of basswood have made a demand for a lower-priced substitute, but none seems available which is as suitable.

The wooden soles of clog shoes are often of basswood. Such shoes have leather tops and are for use in wet and cold places, such as tanneries, creameries, mines, dye works, fish canneries, slaughter houses, paper mills, and in foundries and metal works. They are also used where a durable, low-priced shoe is desired. Yellow poplar is often used in place of basswood for wooden soles. A high quality of wood is required for these products, and the percentage of waste is high, especially in the use of thick stock or billets for the manufacture of the shoe forms.

New York, Massachusetts, Maine, and Michigan reported the largest quantities of basswood used for these purposes.

CASKETS AND COFFINS.

Basswood is used in several ways in the construction of caskets and coffins. It is made into cheap caskets and coffins, which are often stained to imitate more expensive woods; and it is well adapted for use in this way, because it is easily worked and finishes well. It is also frequently used for the cloth-covered casket. Its main use in the industry, however, is as a core wood for panels of expensive caskets covered with veneer and for moldings and carved work on such caskets. The outer case, usually called "rough box," which also often serves as a shipping case for the casket, is sometimes made of basswood because of the good appearance of the wood.

A large number of States reported comparatively small quantities of basswood used for this purpose.

PROFESSIONAL AND SCIENTIFIC INSTRUMENTS.

Basswood is well liked for many professional and scientific instruments because of its good color, ease of working, and light weight. It is a favorite wood for yardsticks and rulers because it shows printing to advantage and does not warp. Manufacturers of advertising novelties use large quantities of basswood, particularly for yardsticks on which advertising matter is printed. Drawing boards and the tops of draughtsmen's tables have certain requirements which must be met if they are to be satisfactory. The wood must be soft so that the thumb tack used to fasten the sheet in place

can be driven in with the pressure of the thumb and can be easily withdrawn; at the same time the wood should hold the thumb tack in place. Such boards are often made of several plies to obviate any tendency of the wood to warp or split. Basswood is a preferred wood, and yellow poplar is also satisfactory; white pine, sugar pine, and redwood are much used for this purpose. Because of its suitability for printing, alphabet blocks of basswood are made in large quantities. It is also employed in the manufacture of cameras, the wooden box and other small wooden parts of such instruments consuming large quantities in the aggregate. Boxes for holding various professional and scientific instruments, including carpenters' tool chests and optical instrument cases, are often of basswood. Pasteboards for paper hangers are also made of this wood. It is used for cigarmakers' molds, because it is readily carved, and as labels for potted plants on which writing or printing must show well. Pencils and penholders of basswood are stained to give an attractive appearance. It also serves for spirit levels and the backs of thermometers.

More than two-thirds of the entire amount of basswood reported to the Forest Service by manufacturers for these uses was consumed in New York State.

HANDLES.

Basswood is not adapted for handles of such tools as axes, sledges, forks, and hoes, because it lacks the necessary strength. It is used in considerable quantities, however, for broom and mop handles, and for the long handles of window brushes. For short handles of trowels, soldering irons, and files it serves very satisfactorily, and also for the handles of engravers' tools. Harder woods, such as beech, birch, and maple, are generally more satisfactory than basswood for such handles, however, because they are stronger, wear better, and do not split so readily.

Ohio and Michigan reported the largest quantities of basswood for handle manufacture.

SHUTTLES, SPOOLS, AND BOBBINS.

Basswood is the sixth wood in importance in the shuttle, spool, and bobbin industry, birch and maple being most largely used. Basswood is made principally into the one-piece spool for holding thread or tape, and for the ends or disks of three-piece spools, which are much larger and are used in textile mills. Paper or white birch is most commonly used for these spools; but basswood is satisfactory, because it turns well and makes a spool that looks well.

The bulk of the basswood used in this industry was reported by Massachusetts and New Hampshire.

CHAIRS.

Although basswood ranks about tenth in amount among the woods used for chairs, it is not considered an important chair wood because such material should in general be able to stand loads and shocks. Its use is mainly for seats, seat frames, and backs of cheap chairs, where it serves in the form of plywood, and in high-priced work, such as cores for panels.

CLOCKS.

Basswood is second in importance among woods used for clocks, oak being consumed in larger quantities. Basswood is much used for hidden work and the backs of cases; it is a favorite wood for cases finished in enamel work, and is popular in the imitation of foreign woods, marble, and other materials. Basswood also serves as core wood for figured veneer work, which is much used in clock cases.

Connecticut reported the bulk of the basswood used for clock manufacture.

MACHINE CONSTRUCTION.

The amount of basswood used in the construction of machines is surprisingly large, considering that a high degree of strength is generally required for this purpose. Basswood finds its use in this industry mainly for boxes and spouts, such as are used in flour-mill machinery, and for woodwork of looms and parts for which a light, soft wood is desirable.

SHIP AND BOAT BUILDING.

Basswood finds a useful place in ship and boat building mainly as a finish material. It is well adapted for moldings and other woodwork for the interior of cabins, especially where finished in enamel. It is put to a large number of other uses.

BRUSHES.

Basswood stands fourth in importance among woods used in brush making. Beech, birch, and hard maple are each used in much larger quantities. These woods are more desirable for this use because of their greater hardness and resistance to splitting. Basswood generally goes into the cheaper, rough, unpolished handles, while the other woods mentioned are used in the manufacture of higher-grade articles.

SHADE AND MAP ROLLERS.

The chief use of basswood in the shade and map roller industry is for curtain poles. It serves well for this use, because it is so easily worked and because the ease and permanence with which it takes paint and stain allow it to be finished to imitate expensive hardwoods,

such as walnut, mahogany, and oak. Rug and drugget poles, which are lower-grade products, are also made of basswood. This wood is not adapted for heavy poles, for which maple, birch, oak, and ash are more serviceable. Some basswood is used for window-shade rollers, but white pine is the usual wood employed for this purpose. Awning poles are often of basswood, because a light-weight wood is desirable.

PULLEYS AND CONVEYORS.

Basswood is used for the rims of wooden pulleys, because it is light in weight, has good gluing qualities, holds nails well without splitting, and does not shrink, swell, or warp greatly. Wooden pulleys are preferable in many cases to those of metal, because the lighter weight renders them less likely to break through centrifugal force. These rims are generally built up of a large number of pieces, which are carefully fitted and glued together. Since basswood will not stand a large amount of wear, harder and therefore heavier woods are used in larger quantities.

Basswood is employed in the construction of buffer wheels, such as are used for polishing metal and glass; and it is preferred for this use, because it is fine-grained and holds the polishing materials well. These wheels are usually made up solid of about six pie-shaped pieces, which are dove-tailed and glued together, making a strong, light-weight disk.

PRINTING MATERIAL.

The use of basswood in the printing industry is mainly for parts of printers' type cabinets and as base blocks for rubber-stamp pads. It commonly serves as bottoms of type boxes or trays, often in the form of veneer; for the latter use a low-grade material is employed.

SPORTING AND ATHLETIC GOODS.

Basswood serves to advantage for the inside framework of billiard and pool tables, because it holds its shape well. It is also employed to a considerable extent for fishing-line blocks on which the line is wound, because of its light weight.

SEWING MACHINES.

For sewing-machine cabinets, basswood is used to advantage as a corewood for expensive veneers, and as sides and bottoms of drawers and compartments, where its white, cleanly appearance makes it a preferred wood.

ELECTRICAL MACHINERY AND APPARATUS.

In the making of electrical apparatus basswood is used especially for spools for holding small-gauge wire, for base blocks, and for parts of such electrical apparatus as telephone cabinets.

PLUMBERS' WOODWORK.

Basswood is adapted for toilet and medicine cases or cabinets, towel cabinets and racks, and other cabinet work for toilets, which may be finished in basswood and painted in imitation of more expensive woods, or enameled to match the tile work of the room. Such cabinets are more often finished in a more decorative wood, such as white oak or birch.

DOWELS.

For wooden pins used to hold wooden parts together, mainly in cabinet work, basswood is a preferred wood, because of its good turning qualities. Where the parts are subjected to much strain, stronger woods, such as birch, beech, and maple, are required; and these are the principal species used.

PATTERNS AND FLASKS.

Basswood is a very suitable wood for patterns, because it is so easily worked, keeps its shape, and does not split easily. It is used mainly in shop patterns, and it is well liked for templets in shipbuilding. High-grade, fairly clear stock is required for this use.

SIGNS AND SUPPLIES.

Since basswood shows painting and printing to such advantage, it is well adapted for small signboards. White pine, however, is the favorite wood for this purpose and is more durable in situations exposed to the weather. Basswood signs should be kept painted in order to give good service.

SADDLES AND HARNESS.

Basswood is valuable for saddletrees, because it is light in weight, strong for its weight, and is easily modeled into various forms. It is adapted for light-weight saddles; for those requiring a high degree of strength, such as the pack saddle and the cowboy saddle, heavier and tougher woods are required. Clear, high-grade, thick stock is utilized for this purpose. Basswood is also used for stirrups, in which it serves for the head or neck blocks.

MARKETS.

On account of its growing scarcity and the high value placed upon it for special uses, there is usually little difficulty in finding a ready market for basswood timber. It is commonly sold in the form of lumber, log, and bolt. Where the timber stands are far distant from the factory, basswood is generally manufactured into lumber along with other hardwood species with which it grows in mixture. Cooperage and woodenware plants, however, in some instances buy tracts of timber from which they log the basswood and other species. In

sections of the country where factories using basswood are located, logs, bolts, and lumber generally find a ready sale. As a rule, it is preferable for the small timber owner to market basswood timber in the log rather than to saw it into boards and planks, because the factories using logs can utilize the timber in this form to much greater advantage (Pl. VI).

Basswood logs are marketed to best advantage in the winter time, because the timber is less apt to become stained and decayed in cold weather through the action of molds and wood-destroying fungi. In warm weather logs should not be allowed to lie in contact with the ground for more than a few days, but should rest on skids, and should not remain in a damp situation for an extended length of time, because basswood deteriorates very rapidly under such circumstances. Farmers usually find it most convenient to cut their timber and haul it to the railroad during the winter months. In disposing of their timber, owners of small tracts will find it to their advantage to get in touch with their State forestry departments in order to obtain names of possible purchasers, prices, and specifications.

Since many firms quote prices at the mill or factory, the following weights of basswood in various forms are given, from which freight costs may be figured:

	Pounds.
Rough lumber, 1 inch thick, 1,000 board feet:	
Green	[3] 4,200
Dry	[3] 2,500
Logs, 1,000 board feet, log scale, Doyle Rule:	
Diameter inside butt at small end, 6 inches—	
Green	43,800
Dry	27,800
Diameter inside butt at small end, 12 inches—	
Green	9,400
Dry	6,000
Diameter inside butt at small end, 18 inches—	
Green	6,600
Dry	4,200
Diameter inside butt at small end, 24 inches—	
Green	5,600
Dry	3,500
Bolts, butts, etc., 1 cord of 128 [4] cubic feet:	
Green	3,700
Dry	2,300

LUMBER.

Basswood lumber, if well manufactured, is readily salable to a large number of industries. High-grade stock is in demand by manufacturers of musical instruments, apiarists' supplies, and cigar boxes. For piano keys, thick stock is required which should be white

[3] Official standard weights of the National Hardwood Lumber Association.

[4] Figured on the basis of 90 cubic feet of solid wood content.

in color. The white stock is also demanded for bee-keepers' supplies, for which the No. 1 common grade is often purchased. Firsts and seconds is the usual grade for the manufacture of cigar boxes. The combined grade of No. 2 common and better grades is probably most commonly used, especially by factories making toys, trunks, kitchen cabinets, and dairymen's and apiarists' supplies. For planing-mill products, sash, doors, blinds, and general millwork, a good grade of lumber is employed. For boxes and crates, lower grades are employed as a rule, usually Nos. 2 and 3 common. No. 1 common is also sometimes used.

Furniture and trunk factories use basswood very largely in the form of built-up stock, which is generally the product of the veneer mill.

LOGS.

The higher-grade logs are purchased by mills cutting veneer for various products. Factories making panels for trunks, furniture, and cabinets of various kinds require logs of good quality which must be reasonably clear, straight, and round, so that they will cut to advantage into rotary veneer (Pl. VI). These factories will take hollow logs if the log is otherwise of good quality. The hollow portion of such logs must, of course, not be too large and there must be a thick rim of sapwood around it (Pl. VIII). The minimum diameter of logs purchased by these veneer plants is usually 10 inches. For the No. 1 or veneer log grade about $35 to $40 is the usual price paid at the factory.

Some of the veneer plants, including those manufacturing lower-grade products, such as cheese boxes, also have a sawmill equipment and convert lower-grade logs into lumber, which they use in the manufacture of their products. They buy woods-run logs, which bring about $20 to $30 a thousand board feet f. o. b. cars. The price at the factory is generally $5 to $8 a thousand more. Basket factories generally pay somewhat less. In some instances they purchase sizes down to 6 inches in diameter at a comparatively low cost. Match factories using basswood require logs of high quality for veneering. They generally use No. 1, or veneer, grade, which must be free from black heart-rot and reasonably free from knots. Sizes down to 8 inches in diameter and 22 inches in length are taken. The specifications usually call for 8 to 12 inch diameter material in lengths which are multiples of 22 inches up to 15 feet. Logs over 12 inches in diameter are preferred in lengths between 3½ and 14 feet. No. 1 logs cost match factories about $50 to $55 a thousand board feet, freight included. No. 2 logs suitable for this purpose bring $5 to $10 a thousand less. Match factories must frequently get their logs from a considerable distance, and the resultant high freight costs often amount to from $10 to $15 a thousand board feet.

Large cooperage and woodenware factories get their timber very largely from their own tracts. Small firms must usually depend on purchase from various sources. Cooperage factories use logs 7 inches and over in diameter at the small end for barrel heading. Factories making pails and tubs use the largest quantities of basswood. They generally prefer woods-run logs, for which they pay about $30 a thousand board feet on board cars at loading point, taking sizes down to 6 inches in diameter at the small end (Pl. VII). Lengths of 8 to 10 feet are preferred, but shorter lengths of about 3 feet are often purchased. Some firms buy only No. 2 logs, which are small and largely defective, often with hollow centers, and pay about $15 a thousand board feet loaded on cars. Logs 6 inches and up in diameter are taken if not too defective, and even some 4-inch sizes are accepted if they are of good quality. Hollow logs with a 4-inch shell are taken by some factories if they are otherwise sound. Second-growth, clear, white basswood is preferred by these factories because it makes a much more attractive pail. Last-block manufacturers purchase basswood logs as small as 12 inches in diameter at the small end. Factories making ladders sometimes buy basswood in the log also.

Box factories in many instances buy basswood in the log. The logs are also frequently used for the manufacture of vegetable crates.

BOLTS.

Basswood in bolt form is used by excelsior and pulpwood plants. Excelsior wood should be of good quality, sound, reasonably straight, and free from knots. Lengths of 36, 37, 54, and 55 inches are the most common ones specified, and a minimum diameter of 4 inches is accepted. Diameters of 7 to 12 inches are required to be split in half, over 12 inches split into four pieces, and very large sizes split in proportion. Some firms require that the large bolts be split to the heart into pieces 6 to 8 inches wide on the bark side. Excelsior wood is usually purchased green and unpeeled or dry and peeled. Some factories accept peeled stock in the green or partially air-seasoned condition. Usual prices paid for 36 and 37 inch lengths are $3 to $4 a cord with bark, and $4 to $5 peeled; for 54 and 55 inch lengths the prices are proportionately greater. The cord for all lengths given is 4 feet high and 8 feet long. These prices are for wood on board cars at loading point. The price at the factory is usually 50 to 75 cents a cord more for 37-inch wood. Excelsior wood should not be allowed to dry with the bark on, because it can be barked satisfactorily only when the wood is green. Wood which has thoroughly air seasoned is most acceptable; ordinarily it should not stand more than two years, however, as it may become brittle and is likely to be attacked by decay, which impairs its value. If it is to stand in piles for any

length of time, it should rest on poles or sticks to keep it off the ground. A space of about 2 feet should be left between piles to allow it to dry properly. Kiln-dried wood, if subjected to too high temperatures, often exhibits a brittleness when cut into excelsior, which makes it less desirable than the air dried. It is often very profitable for the small timber owner to convert his basswood trees into excelsior wood rather than to market them in other forms, because the small-diameter material and limbs can be more closely utilized.

Basswood is also valuable as pulpwood, for which use it is purchased at the same price as poplar. It is used for pulp mainly in the southern Appalachians. Specifications call for 5-foot lengths, with a minimum diameter of 4 inches. Bolts 4 to 7 inches in diameter are not to be split, more than 7 and up to 10 inches in diameter to be split once, more than 10 and up to 14 inches quartered, and above 14 inches to be split in proportion. Basswood pulpwood usually brings about one dollar more per cord than beech, birch, and maple pulpwood.

Woodenware factories, particularly those making pails and tubs, frequently buy bolts with a minimum diameter of 4 inches to 6 inches. Lengths are usually 40 and 52 inches. In some cases longer lengths are accepted. The price paid on cars at loading point ranges from about $6.50 to $8 per cord and the freight amounts to $1 to $2 a cord more. Second-growth timber is preferred. Box factories in some instances buy basswood bolts for conversion into crating. They take diameters down to about 6 inches, and 52-inch lengths are usually preferred.

Where the timber runs small in size, and especially on cut-over tracts, where there is much young, rapid-growth stock, the bolt is the practicable form for marketing.

SUMMARY.

Basswood is an important commercial timber of the northeastern part of the United States. Since it grows in mixture with other hardwood species and does not form dense stands, it has never been a very plentiful timber. In regions where it was formerly comparatively abundant, particularly in New York, Pennsylvania, and Ohio, various industries have greatly reduced the supplies available, so that it is now scarce in these States. The Great Lakes and southern Appalachian regions are now the main sources of the timber. Wisconsin and Michigan have furnished the largest quantities for the last 20 years. During the last 12 years the quantities used have diminished greatly; the amount of basswood lumber manufactured during this period has been reduced by about 50 per cent. The period of maximum lumber production was from 1906 to 1910; in

each of the years 1906, 1907, and 1909 the total amount of basswood lumber cut was about 400,000,000 board feet. At present the total annual use of basswood for all purposes probably does not exceed 250,000,000 board feet. The total stand of basswood timber is estimated to be about 9,000,000,000 board feet.

Basswood is valued mainly for its light color, light weight, and good working and seasoning qualities, and because it shows printing to advantage. It is used mainly for wooden containers and utensils which come in contact with food, including boxes, barrels, pails, tubs, and kitchen woodenware. Cabinetwork and inside finish of buildings are also important uses.

Raw material is used in the form of the log, bolt, and lumber. Logs are used for the production of veneer, which is made into plywood for trunks, furniture, and other cabinetwork. Logs are also converted into veneer for cheese boxes. Basswood in the log is used for the manufacture of matches by the veneer process. Logs are also used in large quantities for making pails, tubs, and slack-barrel heading. The bolts are used mainly for conversion into excelsior and pulpwood. The principal uses in the form of lumber are for boxes, inside finish, apiarists' supplies, laundry appliances, and toys. Its most exacting use is for honey sections to hold comb honey, for which purpose a white wood is required. Basswood is an ideal wood for candy pails and cracker and candy boxes, because of its clean appearance and light weight and because it does not taint substances in contact with it. Its light color also makes it very much in demand for flour-barrel heading, cheese boxes, excelsior, pulpwood, and laundry appliances, including mainly washboards and ironing boards. Its lightness and good seasoning and gluing qualities make it an excellent core wood, producing a strong, light panel. Because of these properties it is the preferred wood for trunks.

Basswood generally finds a ready market in the form of the log or bolt, or as lumber. For the small timber owner the log and bolt are the most advantageous forms for marketing. Large, clear, high-grade logs bring the best prices when sold for conversion into veneer. Small and low-grade logs and bolts can be disposed of most profitably to woodenware and slack-cooperage factories. Clear, small-dimension stock can be sold to best advantage to excelsior and pulpwood plants. It is desirable to obtain information on prices, specifications, and methods of measurement from prospective purchasers before the standing timber is converted into marketable form.

Since basswood reproduces easily and increases in size rapidly in situations favorable for the growth of the tree, and since the timber is readily marketable in various forms, owners of land suitable mainly for timber production in the basswod region will find it advantageous to encourage the growth of this species.

APPENDIX.

Classified list of uses reported for basswood by factories.

AGRICULTURAL IMPLEMENTS.

Alfalfa grinder parts.
Corn grader frames.
Corn huskers.
Corn planters.
Corn shellers.
Fanning-mill drums.
Fanning mill sieve frames.
Fanning mills.
Feed grinders.
Feed mills.
Feeder slats.
Garden cultivators.
Grain cleaners.
Grain hoppers.
Grass seeders.
Grass-seeder boxes.
Hay loaders.
Hayracks.
Hayrake parts.
Hullers.
Peach graders.
Potato planters.
Seeder boxes.
Separators:
- Bean.
- Grain.
- Threshing machine.

Tanks, threshing-machine.
Thrasher boxes.
Threshing machines:
- Dust conveyors.
- Tanks.

Threshers:
- Braces.
- Grain pans and shakers.
- Grain registers.

Wheat fans.

BOOT AND SHOE FINDINGS.

Hollow lasts.
Lasts.
Shoe clog soles.
Shoe fillers.
Shoe forms.
Shoe frames.
Shoe lasts.
Shoe trees.

BOXES AND CRATES.

Baskets:
- Berry.
- Clothes.
- Fruit and vegetable.
- Grape.
- Split.

Basket covers.
Basket hoops.
Basket splints.
Boxes:
- Berry.
- Bottle.
- Bread.
- Butter.
- Candy.
- Chocolate.
- Confectionery.
- Druggist.
- Fancy.
- Folding.
- Fruit.
- Glove.
- Knife.
- Lock-corner.
- Mailing.
- Novelty.
- Packing.
- Polished.
- Poultry.
- Printed.
- Rubber type.
- Shirtwaist.
- Tool.
- Type.
- Utility.

Box shooks.
Cases:
- Egg.
- Packing.
- Shipping.
- Type.

Crates.
Crates, bushel.
Crating.
Lids, grape-basket.
Tea chests.
Trays, egg.

BOXES, TOBACCO.

Cigar boxes.
Humidors.
Tobacco boxes.

BROOMS.

Broom handles.

BRUSHES.

Brush:
- Backs.
- Blocks.
- Handles.

Brushes.

BUTCHERS' BLOCKS AND SKEWERS.

Skewers.

CAR CONSTRUCTION.

Car finish, outside.
Car:
- Repairing.
- Roofing.

Cars:
- Freight.
- Interior finish.
- Railroad.

Ceiling, car hood.
Dust guards:
- Freight cars.
- Railway cars.

Locomotives.
Locomotive woodwork.
Passenger cars:
- Interior finish.
- Interior work.

Railroad coaches.

CASKETS AND COFFINS.

Caskets.
Caskets:
- Cases.
- Corners.
- Molding.
- Panels.

Coffins.

CHAIRS.

Chair seats.
Chairs.
Seat frames.

CLOCKS.

Clock cases.

COOPERAGE.

Heading:
- Barrel.
- Slack cooperage.

Spice kegs.
Staves.
Staves:
- Slack cooperage.
- Tight cooperage.

DAIRYMEN'S, POULTERERS', AND APIARISTS' SUPPLIES.

Beehives.
Beehive sections.
Bee boxes.
Butter molds.
Honey boxes.
Churns:
- Covers.
- Standards.

Honey crates.
Honey sections.
Incubators.
Poultry coops.
Poultry coops, bottoms.
Poultry crates.

DOWELS.

Dowels, furniture.

EQUIPMENT, PLAYGROUND.

Exercise rings.
Swing seats.

EXCELSIOR.

Excelsior.
Excelsior:
- Mattress stuffing.
- Packing.

FIXTURES.

Alarm tills:
- Bottoms.
- Tops.

Altars, church.
Bank fixtures.
Cabinet drawers.
Cabinets.
Cabinets:
- Seed.
- Toilet.

Church furniture.
Church pews.
Cupboards.

Cupboards:
- Backs.
- Bottoms.
- Drawers.

Desks, school.
Die cases.
Display forms:
- Hosiery.
- Shoe.

Fixtures:
- Bank.
- Bar.
- Barber shop.
- Drug store.
- Office.
- Store.
- Store and office.

Frames, store fixture.
Interior frames, store fixture.
Medicine cabinets.
Medicine cases.
Pews, church.
Racks:
- Curtain display.
- Rug display.

Shoe cases.
Shoe racks.
Show cases, inside work.
Stands, Bible.
Stock racks.
Wall cases.
Water-closet, tank backs.

FRAMES AND MOLDING, PICTURE.

Frames:
- Mirror.
- Picture.

Molding, picture.

FURNITURE.

Backing:
- Enameled work.
- Mirror.
- Furniture.

Backs:
- Buffet.
- Bureau.
- Chiffonier.
- Chifforobe.
- Mirror.
- Wardrobe.
- Washstand.

Bedsteads, hidden work.
Bookcase backs.
Bookcases.
Bookcases, inside work.
Bottoms:
- Buffet.
- Case.
- Chiffonier.
- Dressers.

Card-table tops.
Carvings, wood.
Chamber suites.
Chest bottoms.
Chests, interior
Chiffoniers.
China closets.
China closets, interior.
Commodes.
Consoles.
Couches, box.
Couch bottoms.
Couch frames.
Drawer bottoms.
Drawer sides.
Dresser backs.
Dresser drawers.
Extension tables.
File cases.
Filing cabinets, tops and shelves.
Frames:
- Couch.
- Davenport.
- Lounge.
- Spring-bed.

Furniture:
- Case goods.
- Dining room.
- Hidden work.

Interior work:
- Furniture.
- Office desks.

Lawn furniture.
Letter files.
Lodge furniture.
Looking-glass backs.
Music cabinets.
Music cabinets, interior.
Novelty furniture.
Parlor furniture, frames.
Rails:
- Door.
- Table.

Record cabinets.
Serving tables, hidden work.
Shelves, desk.
Showcase tables.
Sideboards, interior work.

Slats, bed.
Stands, typewriter.
Store and office furniture, interior work.
Tables.
Tables:
- Extension.
- Inside parts.
- Inside work.

Table parts.
Table tops.
Tabourettes.

HANDLES.

Handles:
- Broom.
- Brush.
- Dipper.
- Engravers' tool.
- File.
- Long-handled dust broom.
- Mop.
- Pipe.
- Plastering trowel.
- Street brush.
- Trowel.
- Wall brush.
- Window brush.

INSTRUMENTS, PROFESSIONAL AND SCIENTIFIC.

Cameras.
Chalk triangles, schoolroom.
Drawing boards.
Engraving boards.
Glass-cutters' boards.
Medical batteries.
Pencils.
Pen holders.
Quills.
Rulers.
Saw frames.
Scales.
Spirit levels.
Thermometers.
Trays, enameling.

INSTRUMENTS, MUSICAL.

Bellows:
- Organ.
- Piano-player.

Bellows, organ, frames.
Blowers:
- Organ.
- Piano-player.

Bottom panels, piano-case.
Case parts, piano.
Cases:
- Band-instrument.
- Cornet.
- Drum.

Cheeks, piano-case.
Drums.
Fall boards, piano-case.
Guitars.
Key blocks.
Key bottoms, piano-case.
Key slips, piano-case.
Keys, piano.
Keys, piano (key racks).
Mandolins.
Mandolin necks.
Molding, piano-case.
Music shelf, piano-case.
Organs.
Organ backs.
Organ cases, folding organs.
Organ frames.
Organ keys.
Pedal cases.
Pianos.
Piano backs.
Piano cases.
Piano cases, sides.
Piano fronts.
Piano players.
Piano skeletons.
Pilasters, piano-case.
Pipe organs, interior parts.
Pipe organs.
Pipes, organ.
Rails, piano.
Tops, piano.
Top panels, piano-case.
Veneer cases, piano.
Violin cases.

LAUNDRY APPLIANCES.

Clothes bars.
Clothes driers.
Clothes pins.
Clothes racks.
Curtain stretchers.
Ironing boards.
Ironing boards, folding.
Ironing-board tops.
Laundry machinery.
Laundry machines, hydraulic.
Stretchers, curtain.
Stretching horses.
Tables, ironing.
Tubs, washing-machine.

MACHINE CONSTRUCTION.

Clay-working machinery.
Coal boxes, traction-engine
Coffee mills.
Cotton gins.
Engine jackets.
Flour-mill machinery.
Jack screws.
Loom ribs.
Loom shafts.
Looms.
Machinery bodies.
Machinery construction.
Mud shields, traction-engine
Presses:
    Cider.
    Wine.
Reed ribs, loom.
Road machinery.
Smut mills.
Spouting, flour-mill.

MACHINERY AND APPARATUS, ELECTRICAL.

Apparatus, electrical.
Fans, electric.
Spools, wire.
Telephone accessories.

MATCHES AND TOOTHPICKS.

Match sticks.

PATTERNS AND FLASKS.

Patterns.
Shop patterns.
Templets:
    Boat.
    Shipbuilding.

PLANING-MILL PRODUCTS.

Astragals, sliding-door.
Balusters.
Baseblocks, house interior trim.
Baseboards.
Baseboards, house interior trim.
Base corners, house interior trim.
Base molding, house interior trim.
Beams, dining-room ceiling.
Binding strips, school blackboard.
Book shelving.
Carpet strip. house interior trim
Casing.
Casing:
    Door.
    House.
    Window.
Ceiling.
Chair rail, house interior trim.
Finish.
Finish:
    Exterior.
    Interior.
Flooring.
Interior finish:
    Buildings.
    Churches.
Interior woodwork.
Molding:
    Bed, house construction.
    Cap, house interior trim.
    Cove.
    Crown, house interior trim.
    Drip cap, house construction.
    Electric wire.
    Plaster, house construction.
    Spring cove, house construction.
Nosing, house interior trim.
Parting strip, house interior trim.
Partitions.
Partition molds, house interior trim.
Plate rail, dining room.
Sheathing.
Shiplap.
Siding.
Siding, house.
Weather boarding.

PLUMBERS' WOODWORK.

Cabinets, toilet.

PRINTING MATERIALS.

Engraving boards.
Printers' cabinets.
Printers' supplies.
Rubber-stamp pads, base blocks.

PULLEYS AND CONVEYORS.

Pulleys.
Rims, split-wood pulleys.
Split pulleys.

REFRIGERATORS AND KITCHEN CABINETS

Backs, kitchen cabinets.
Bread boards, kitchen cabinets.
Drawer bottoms, kitchen cabinets.
Kitchen cabinets.
Kitchen cabinets, interior work.
Kitchen tables.
Refrigerators.
Shelving, kitchen cabinet.
Table tops, kitchen cabinets.
Tops, kitchen table.

SADDLES AND HARNESS.

Saddletrees.
Stirrups:
    Head blocks.
    Neck blocks.

SASH, DOORS, BLINDS, AND GENERAL MILLWORK.

Blinds.
Blinds, window.
Bottom rails, sash.
Brackets, plate-rail.
Butchers' coolers.
Capping, sink (house interior trim).
Case work.
Colonnades, house, interior trim.
Corner blocks, house interior trim.
Cornices, door.
Doors:
    Folding.
    Sliding.
Dust cap, house interior trim.
Frames:
    Front door, side light.
    Window.
Front doors, house.
Grilles.
Grilles, house, interior trim.
Head blocks, house interior trim.
Head casing, house interior trim.
Jambs, door.
Mantels.
Mantels, painted work.
Meeting rail, sash.
Millwork.
Mirror doors, house.
Mullions, sash.
Panel strips, house interior trim.
Panels, door.
Porch columns.
Porch work.
Rails, door.
Sash.
Sash, window.
Screens.
Screens, window.
Sink aprons, house interior trim.
Stair work.
Stiles, door.
Stops, door (house interior trim).
Stops, window (house interior trim).
Top rails, sash.

SEWING MACHINES.

Sewing-machine cabinets.

SHADE AND MAP ROLLERS.

Curtain poles.
Rug poles.
Window-shade rollers.

SHIP AND BOAT BUILDING.

Boats.
Shipbuilding.

SHUTTLES, SPOOLS, AND BOBBINS.

Bobbins.
Spools.
Spool heads.

SIGNS AND SUPPLIES.

Signboards.
Signs, advertising.

SPORTING AND ATHLETIC GOODS.

Automatic bowling alley bottoms.
Billiard-table beds.
Fishline blocks.
Indian clubs.

TANKS AND SILOS.

Silos.
Tanks, water.

TOYS.

Animals, toy.
Automobiles.
Blackboards.
Boats, toy.
Cannon and fort sets.
Circus sets.
Dolls.
Doll houses.
Doll parts.
Game boards.
Games.
Hand-sled tops.
Hobbyhorses.
Hobbyhorses, stick.
Horse rockers, children's.
Parlor games.
Pianos, children's.
Seats, tricycle.
Shooting galleries.
Sled tops.
Sleds.
Stocks, popgun.
Wagon, toy (sides).
Wheelbarrows.

TRUNKS AND VALISES.

Boxes, trunk.
Frames, suitcase.
Sample cases.

VEHICLES AND VEHICLE PARTS.

Automobile bodies.
Automobile panels.
Automobile roof and top slats.
Baby carriages.
Baby-carriage bodies.
Baby tenders.
Battery boxes, automobile
Bent vehicle parts.
Brake blocks.
Buggy bottoms.
Buggy repairs.
Business-wagon bodies.
Carriage bodies.
Carriage panels.
Carts, dump.
Delivery-wagon panels.
Desks, mail-wagon.
Doubletrees.
Frames, buggy-cushion.
Go-carts.
Panels, light vehicle bodies.
Panels, vehicle seats.
Panels, light vehicle seats.
Sideboards, wheelbarrow.
Sides, wagon-body.
Sides, wheelbarrow.
Singletrees.
Slats, wagon-top.
Sleigh bodies.
Sleighs.
Street-sprinkler parts.
Surrey-canopy frames.
Vehicle body panels.
Wagons.
Wagon dashes.

WHIPS, CANES, UMBRELLA STICKS.

Sticks, umbrella.

WOODENWARE AND NOVELTIES.

Boards:
- Bread.
- Carving.
- Cloth.
- Hosiery.
- Meat.
- Pastry.
- Potato chip.
- Potato peeler.
- Skirt.
- Slaw.
- Sleeve.

Book blocks.
Bowls.
Boxes, cheese.
Bucket bottoms.
Bucket covers.
Buckets, candy.
Buckets, sugar.
Butter ladles.
Candlesticks.
Carved woodenware.
Checkers.
Checks:
- Barbers'.
- Haybalers'.

Coat hangers.
Dominoes.
Envelope holders.
Fish kits.
Flag poles.
Flag sticks, railway.
Fruit driers.
Globes, geographers'.
Handles, fan.
Heading, cheese-box.
Jewelry-case frames.
Kitchenware.
Ladders.
Ladders, extension.
Ladders, step.
Lapboards.
Lard tubs.
Matchsafes.
Match strikers.
Novelties.
Novelties, burnt-wood.
Pails:
- Candy.
- Fish.
- Lard.

Panorama, religious.
Paper racks.
Porch shades.
Pyrography.
Reels, electric-wire.
Reels, solder-wire.
Seed cabinets.
Shredders.
Silverware cases.
Snow shovels.
Soap cups.
Souvenirs.
Step-ladder steps.
Strips, felt-bound (school slates).
Towel-roller frame.
Towel rolls.
Tub bottoms.

UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 1008

Contribution from the Bureau of Entomology

L. O. HOWARD, Chief

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RATE OF MULTIPLICATION OF THE HESSIAN FLY.

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INTRODUCTORY AND HISTORICAL.

In the course of investigations of the Hessian fly (*Phytophaga destructor* Say) and its parasites, at the Cereal and Forage Insect Field Station of the Bureau of Entomology at Carlisle, Pa., it became necessary to have accurate data regarding the normal rate of multiplication of this insect. Such information was needed, in the first place, as a basis for estimating the efficiency of the various species of parasites. In the second place, the writer, having been greatly impressed by the rapidity with which an outbreak of serious proportions may develop in a short time from comparatively small sources, and being aware that such an increase is largely due to the reduction in effect of some of the important natural checks to the increase of the fly, suspected nevertheless that the potential rate of multiplication might be much greater than usually has been supposed.

The writer has been unable to find satisfactory data on this subject in the literature or among other recorded observations. In fact, it appears that little attention has ever been paid to the matter, especially

[1] Died June 23, 1920.

in recent times. In 1861 Wagner[2] by confining a female Hessian fly with wheat plants secured a total of 83 eggs. He evidently carried out other experiments, for he concludes that the number of eggs deposited by a female is more than 80 and less than 100. Koeppen[3] in 1889 stated that, according to Lindemann, a female may deposit up to 200 eggs, but believed these figures too high and gave Haberlandt's statement that the female deposits only from 40 to 50 eggs.

The most careful observations up to the present time seem to be those made by Enock.[4] He confined the female insects in cages with barley plants, securing in one case a maximum of 158 eggs. He also confined females singly in corked vials and secured in this way a maximum of 130 eggs. The number of eggs he secured by these methods ranged from 70 to 158, with an average for 10 cases of 113 eggs. He concludes that a single female lays from 100 to 150 eggs. Although Lugger[5] dissected a female which contained 238 eggs, the usual figures given since the date of the paper by Enock are based on Enock's conclusion. This conclusion, however, resulted from an insufficient number of experiments, and the methods used in obtaining the counts will not give accurate results. The adults of the Hessian fly are extremely sensitive to conditions of temperature and moisture. The females normally oviposit at comparatively low temperatures and when moisture in abundance is present. If these conditions are reversed or if conditions are unsatisfactory in some other respect, the females will die before depositing all their eggs. A new and thorough study of the subject therefore seemed imperative.

METHODS OF INVESTIGATION.

For the reasons stated, the method of confining female Hessian flies in vials and all other methods involving their confinement in cages kept in the laboratory were rejected. Cages kept outdoors at the usual times when adults are abroad were also dispensed with, because any cage modifies natural conditions, more or less, and because it is difficult to secure accurate counts where eggs are scattered over a number of plants.

The writer is convinced that under normal conditions each female deposits practically all of her eggs. It has been found that at the time of eclosion each female contains her normal allotment of eggs in a well-developed condition; in fact, it is possible to count all of the eggs by dissecting the pupa stage. It seemed simpler and more

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[2] WAGNER, BALTHASAR. OBSERVATIONS ON THE NEW GALL-GNAT. Fulda, 1861. Translated in U. S. Entomological Commission, Third Report. Appendix II, B, 1883, p. [15].

[3] KOEPPEN, F. T. DIE SCHAEDLICHEN INSEKTEN RUSSLANDS. St. Petersburg, 1880. Translated in U. S. Entomological Commission, Third Report, Appendix IV, 1883, p. [41].

[4] ENOCK, F. THE LIFE-HISTORY OF THE HESSIAN FLY, CECIDOMYIA DESTRUCTOR, SAY. *In* Trans. Ent. Soc. London, p. 332, 1891.

[5] LUGGER, O. THE HESSIAN FLY. *In* Minn. Agr. Exp. Sta. Bul. 64, p. 552, 1899.

economical of time, therefore, to dissect the females and count the number of ova they contained, and this procedure has been followed out beginning with the fall brood of 1918.

Before the dissection of female flies and the counting of their ova had been carried very far, other difficulties appeared. These hinged chiefly on the question of what females should be counted. At first it seemed simple enough to count the number of ova contained in a given number of females and average up the results. This, however, proved to be insufficient because of the great variation in the results obtained from different lots of females. The females vary greatly in size, and, correspondingly, in the number of ova they contain; and the average number of ova per female varies in different fields.

In the study to determine some of the reasons for this condition of affairs, it became evident that the number of ova contained in a female is related to the number of puparia in a tiller. On the average, the greater the number of puparia in a tiller the smaller the number of eggs the resulting females can lay. Since the average number of puparia in infested tillers varies in different fields and in different years, the difficulty of making a fair average can be readily seen. There also appears to be a relation between the date when wheat is sown and the average number of eggs for females of the fall brood. Puparia obtained from late-sown wheat developed females with a reduced capacity for egg production. When work was begun on the spring brood in 1920 it was found that the average number of eggs varied markedly for the two principal generations. All of these conditions and undoubtedly others have to be dealt with in some manner in arriving at a fair estimate.

In view of these facts, separate counts have been made for the principal generations. In the case of the fall brood all of the puparia found in a number of plants taken from various fields were caged and every female which emerged was dissected. Most puparia were taken from fields known to be sown early and which, consequently, contained flies of all ages; or else they were taken from fields where the age of the plants was unknown. This avoided the giving of undue weight to fields sown late. In this manner many of the data accumulated have been eliminated from the general average for the fall brood.

In the case of the spring brood, all plants were obtained from a number of fields just before harvest. All their puparia were removed and caged. In two cages extremely long stubbles, which probably contained all the puparia of the original plants, were used. In this generation allowance must be made for an enormous mortality due to parasitism and weather. Usually it is not expected that more than from 3 to 10 per cent of the flies will remain alive at emergence time in the fall, and, of course, allowance must be made

for males which are sure to emerge. Taking all of these facts into consideration, success beyond expectations was achieved in the fall of 1919, in making counts for the spring brood of 1920.[6]

AVERAGE NUMBER OF OVA FOR THE PRINCIPAL BROODS.

In presenting the results of this investigation, it will be necessary to consider first the average number of ova which can be laid by females of the principal generations. The data for each of these generations will be tabulated separately. After this has been done, it will be necessary to take into consideration the proportion of the two sexes before a sufficient basis can be had for estimating the rate of reproduction of the Hessian fly.

FALL GENERATION.

In Table 1 are given the results of counting the number of ova contained in 107 females. These flies were obtained from six different fields, as indicated by their cage numbers. It will be noted that the average number of eggs per female varies considerably in different fields, even when the number of females counted is approximately the same. It is thus easy to see what a difficult matter it is to obtain a fair average number of eggs per female. The figures, however, are as fair as could be obtained for the year in question and in the time available.

TABLE 1.—*Average number of ova for females of the fall generation of the Hessian fly, Carlisle, Pa., 1919.*

Cage No.—	Number of females counted.	Number of ova.	Minimum per female.	Maximum per female.	Range.	Average per female.
1620	28	8,014	74	383	309	286.0
1716	26	6,148	33	365	332	236.2
1753	36	13,422	189	464	275	372.8
1755	9	1,361	107	195	88	151.2
1779	6	1,099	134	302	168	183.2
1795	2	658	314	344	30	329.0
Totals	107	30,702	33	464	431	286.9

The actual number of ova per female varies from 33 to 464, with a range of variation of 431 and an average per female of 286.9. It may be added that the smallest female found since this work began belonged to this brood, but to none of the foregoing cage numbers. This female was dissected by Mr. Hill, who found that it contained only 11 ova. The largest female ever found belonged also to this brood. This female was in a different series and contained 474 ova.

[6] In this connection the writer wishes to state that two lots of females of the fall brood were dissected by Mr. C. C. Hill; Mr. P. R. Myers has determined the sex of a large proportion of the flies as they emerged, and both men have helped in collecting and caging the material. All of the work has been done in the laboratory at Carlisle, Pa., and most of the material has been collected near by.

SPRING GENERATION.

For the spring generation the ova have been counted for 160 females. The most surprising thing about the results obtained, as shown in Table 2, is the general average number of ova per female of 232.9. This is an average of 54 eggs per female less than was found in the case of the fall brood.

TABLE 2.—*Average number of ova for females of the spring generation of the Hessian fly; counts made at Carlisle, Pa., in the fall of 1919.*

Cage No.—	Number of females counted.	Total number of ova.	Minimum per female.	Maximum per female.	Range.	Average per female.
1841	57	14,591	79	386	307	256.0
1842	29	6,990	113	372	259	241.0
1869	4	780	34	297	263	195.0
1875	13	3,105	188	350	162	238.8
1876	5	836	71	255	184	167.2
1880	8	1,356	102	214	112	169.5
1881	6	1,048	100	227	127	174.7
1882	2	483	194	289	95	241.5
1883	26	5,965	116	370	254	229.4
1891	10	2,106	108	309	201	210.6
Totals	160	37,260	34	386	352	232.9

While this work has been carried through only one spring generation, it is nevertheless quite evident that this generation is constantly lower than the fall generation in its capacity for egg production. The actual minimum number of ova per female is 34, which is one more than for the fall brood. The maximum, 386, on the contrary, is much lower, and the range of variation is only 352.

SUMMER GENERATION.

While data for the flies developing in volunteer wheat are scant, the results obtained seem interesting enough to be included as Table 3. Only 15 cases are available. In spite of the low average number of eggs, this brood in all probability resembles rather closely the fall generation in the number of eggs it can lay. If this should prove true, it might be that the stage of growth of the plant has an important relation to the size of the flies developing in a plant, and consequently to the number of ova developing.

TABLE 3.—*Average number of ova for females of the generation of the Hessian fly developing in volunteer wheat; counts made at Carlisle, Pa., in the summer of 1919.*

Cage No.	Number of females counted.	Total number of ova.	Minimum per female.	Maximum per female.	Range.	Average per female.
1990	2	524	177	347	170	262.0
2090	13	3,027	54	448	394	232.8
Totals	15	3,551	54	448	394	236.7

SEX RATIO.

Before proceeding further with the discussion of the rate of multiplication, it is necessary to take up the question of the proportion existing between the two sexes. In order to acquire data on this subject, a beginning was made, more than two years ago, to record the sex of all Hessian flies that emerged in the cages. These cages contained only puparia separated from their surrounding plant tissue and reared in small vials. The puparia had been obtained in various localities in the northeastern portion of the United States. In this way the sex has been recorded of practically every fly that has emerged from a few thousand puparia each year. At the end of the first year it appeared that the percentage of females in the spring generation was remarkably high. It was not anticipated that this excess of females in the spring generation would prove to be constant, but Table 4 shows that for the second year the percentage of females dropped only slightly. Although the rearing of flies from the 1919 material has not been completed, a much larger number than usual have already been obtained, and the percentage of females for 1919 is almost the same as for the two preceding years.

TABLE 4.—*The sex ratio in the various Hessian fly generations, 1917, 1918, and 1919.*

Generation.	Year.	Number of males.	Number of females.	Total reared.	Per cent of females.
Spring	1917	168	276	444	62.2
	1918	146	235	381	61.7
	1919	623	1,031	1,654	62.3
Fall	1917	749	761	1,510	50.4
	1918	1,493	1,313	2,806	46.8
Volunteer wheat	1917	246	225	471	47.8
	1918	51	45	96	46.9

For the three years the average percentage of females is 62.1, and it seems quite safe to assume now that at least 60 per cent of the spring brood develop into females. In the case of the fall generation the sexes appear to be approximately equal in numbers, although figures for 1918 are rather low in females. In volunteer wheat there are a very small number of cases from 1918, but it appears in general that the sexes are about equal in the partial broods developed in the summer.

It is now evident enough that the spring brood is the one which shows the greatest variation from normal, both in the high percentage of females produced and in the reduced number of eggs these females can lay. Both may be related phenomena with a common explanation, but this explanation will have to be left to the imagination at the present time.

THE MEANING OF THESE FIGURES.

In order to demonstrate fully the meaning of the figures which have been submitted, two examples will be of considerable help.

Going on the assumption that under normal conditions practically every egg is laid, let it be assumed that none of the fly stages are destroyed by enemies. For the sake of round numbers let 285 be taken as the average number of eggs laid by the fall generation and 230 as the average by the spring generation. It may also be taken for granted that one male will fertilize several females, since Enock[7] proved by careful methods that one male successfully fertilized as many as six females. This will take care of the preponderance of females in the spring brood.

Starting now with a single female of the spring brood emerging in the fall, it is found that she can lay 230 eggs. One-half of these eggs in the spring will produce females, each of which may lay 285 eggs. This will give 32,775 as the product of one female working through two generations in one wheat crop, with no allowance made for multiplication in volunteer wheat. The flies which develop in volunteer wheat in the East are usually comparatively small in number and are heavily parasitized. If it be assumed that all these flies remain alive in the stubbles until the next fall, there will be a total of 60 per cent of the flies emerging as females, or 19,665. If these all lay 230 eggs, there will be the enormous total of 4,522,950 flies developing in the fall wheat of the second year. The resulting females would number 2,261,475 and would give rise in the second spring to 644,520,375 fly stages. This result has been obtained in two crop years, not allowing for any multiplication in volunteer wheat.

The question may be looked at from another point of view. Probably infestation of stubbles is never as low as one puparium per acre, although the foregoing computation began with one fly. In one field studied quite carefully during the summer and fall of 1919 the stubbles were found to be infested at the rate of 4,900,000 per acre. A careful examination of the puparia in these stubbles just before the emergence season showed that only 4.4 per cent contained living fly larvae, parasites having destroyed practically all of the remainder. This 4.4 per cent amounts to 215,600 flies per acre. If 60 per cent of these were females there would be 129,360 females per acre ovipositing in the next crop of wheat and producing in it the next fall 29,752,800 ova. With similar calculations from a few other fields as a basis, a big outbreak in wheat sown in the fall of 1919 was looked for. As a matter of fact, however, it was found after the emergence season was over that many of the expected flies had failed to emerge from the stubbles. A careful count made in the field mentioned above showed that only about one-third of the healthy fly larvæ had transformed. This amounted to about 1.4 per cent of the total number of flies.

[7] Op. cit.

Correcting the figures to correspond with what actually happened in the field and calculating in the same way as before, it is found that this extremely small percentage of flies transforming in this stubble field in the fall would amount to 68,600 flies per acre, with 60 per cent or 41,160 females. These females would lay enough eggs to develop into 9,466,800 flies per acre in young wheat sown in the fall of 1919. This is a much smaller number than had been anticipated, but it will be readily seen that even this is an enormous infestation. If the farmer sows about the same acreage from year to year and no flies are lost by migration, then the flies from an acre of stubbles would proceed to an acre of new wheat. It is calculated that 1,000,000 plants per acre is a good stand, and in that case this farmer would have over nine flies developing on every wheat plant. It will be readily seen from this that his chances of securing a wheat crop under the conditions named are practically zero. It is also evident that anything which helps to cut down this rate of reproduction is of enormous benefit. The principal checks to the multiplication of the Hessian fly are its parasitic enemies and unfavorable weather conditions, and if it were not for them it probably would be impossible inside of two years to grow wheat at all. This illustration, it is hoped, will also help to explain how an outbreak may seem to develop suddenly from a very low infestation of stubbles.

CONCLUSIONS.

The principal points made in this bulletin may be summarized as follows:

1. The rate of multiplication of the Hessian fly is much higher than has been realized.
2. The rate of multiplication is quite different in the two principal broods of the Hessian fly, the spring brood laying on an average only about 230 eggs per female, whereas the fall brood lays about 285 eggs per female.
3. The capacity for reproduction also varies with a number of other factors, such as date of sowing, number of puparia per tiller, etc.
4. Because of these various influences, the actual rate of multiplication will be found to vary from year to year and even from field to field, and in years of light infestation the figures will prove too low.
5. The proportion of males to females varies in the two principal generations. In the spring generation about 60 per cent of the flies are females; in the fall generation the sexes are approximately equal in number.
6. By applying these figures, however unsatisfactory the basis may be, it is believed that entomologists will be better able to appreciate how a Hessian fly outbreak may develop very suddenly, and to predict in a more accurate manner the approach of a dangerous outbreak.

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W. G. CAMPBELL, Acting Chief

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VOLUME VARIATION OF BOTTLED FOODS.

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PURPOSE OF INVESTIGATION.

The amount of variation which occurs in the volume of bottled foods packed under conditions of "good commercial practice" is often the subject of controversy among the bottler, the food official, and the bottle manufacturer. The Bureau of Chemistry has made a number of investigations on this subject. Some of these investigations have been somewhat disconnected, but the gaps existing in the information thus obtained have been filled in, so far as possible, by supplementary investigations. The prevalence of various methods of packing bottled foods, prevalence of the various types of bottles used for foods, prevalence of the different types of bottles manufactured, types of filling machines, methods of manufacture, commercial methods of purchasing and testing bottles, variations in capacity of bottles, variations in volume of contents of bottles of food, and allied subjects have been studied to determine the difficulties involved in packing bottled foods with a uniform quantity of contents. Precaution has been taken to observe the obligations of the bottler, the bottle manufacturer, and the food official to the consumer.

Because the Net Weight Amendment to the Federal Food and Drugs Act and many State laws require that food in package form bear a statement of the quantity of contents, the obligation of the food official to the consumer includes the promotion of the delivery of bottles of food which vary as little as possible from the stated quantity of contents when the possibilities of good commercial practice are taken into consideration. The obligation of the bottler to the consumer calls for an effort to deliver bottled food products, such as flavoring extracts, mineral waters, carbonated and uncarbonated beverages, molasses, honey, maple sirup, vinegar, olive oil, essential oils, table oils, catsup, and salad dressing, which are as uniform in quantity of contents as is commercially practicable. The bottle manufacturer, therefore, is under direct obligation to the bottler and indirect obligation to the consumer to furnish bottles which are as uniform in capacity as it is commercially possible to make them.

It is the purpose of this bulletin to describe a commercial method of bottling which may be considered "good," to calculate maximum variations in the volume of bottled liquids used as foods when packed in accordance with specified good commercial practice, and to present data showing that the calculated maximum variations of the good commercial practice outlined can be met by the bottler.

The results of the investigation here reported are intended to be applicable to liquid foods only.

SOME CAUSES OF VARIATION IN VOLUME OF FOOD IN BOTTLES.

The variation of the quantity of food in the bottle depends on many factors, since various types of bottles are manufactured by various methods and filled by various methods. The causes of the variations are cumulative, extending far back into the history of the bottle. In order to direct attention to the relative weight of some of the causes, certain pertinent factors in bottle manufacturing, methods of bottling, and types of bottles used as food containers are mentioned

BOTTLE MANUFACTURE.

Bottles are manufactured by three processes: Hand, semiautomatic machine, and automatic machine. The processes vary in two particulars—first, the method of gathering the proper amount of glass to be blown into a bottle, and, second, the method of blowing the bottle.

Hand blowing is the oldest and simplest method of manufacture. In this process one end of the punty, a hollow tube about 6 feet long, is inserted in the molten glass and rotated until the amount of glass necessary to produce a bottle of the desired weight has been

collected. The lump of glass attached to the punty is rolled into a pear-shaped lump on an iron plate, placed in a mould, and the glass expanded to the limiting mould walls by blowing through the punty. As soon as the mass has been expanded to the limits of the mould, the punty is detached, the mould opened, and the bottle removed. The neck is then reheated and finished and the bottle placed in a cooling chamber, where the temperature is gradually reduced.

The semiautomatic machine process embodies the first attempts to apply machinery to the blowing of bottles. A stream of glass falling into the mould is cut off by scissors operated by a foot treadle. Since practically all of the glass which falls into the mould is contained in the finished bottle, its weight depends upon the judgment of the operator of the foot treadle. The molten glass is formed roughly in a blank mould by a plunger, and it is then transferred by hand to the blow mould, where it is blown by compressed air to the limits of the walls of the mould.

The automatic machine process accomplishes all steps of bottle manufacture by machinery. The amount of glass is gauged by filling a hollow mould by suction and striking off the excess glass with a knife. The weight of the glass in the bottle is that measured into the mould. After forming the neck of the bottle in this mould the blow mould is brought into position around the pencil of glass, which is expanded to the mould limits by compressed air.

In both hand and semiautomatic machine processes the weights of the bottles are controlled by the accuracies of human judgment, in the first case in properly estimating the weight of molten glass on the punty, and in the second case in properly estimating the amount of glass which drops into the mould. In the automatic machine process the weight of the bottle depends upon the amount of glass measured into the mould by machinery and does not depend upon the accuracy of human judgment. So far as the manufacturing affects the weight of the bottles there are only two processes, hand and machine, the semiautomatic machine process falling into the first class.

In all processes the mould is manufactured according to strict specifications and tests. Its cavity, which controls the exterior dimensions of the bottle, is accurately machined to previously determined dimensions, and sample bottles are blown for weight and capacity tests before it is installed. With continual use a scum accumulates in the mould, slightly diminishing its interior dimensions. After this scum has been removed a sufficient number of times, the mould's dimensions become appreciably larger, so that a new mould must be substituted for it. Much attention is given to the cleaning of the mould and to the possibility of its replacement by the bottle

manufacturer. One of the criteria for changing it is the increased weight of the bottle when bottles of a definite capacity are being blown.

To assist him in keeping the weight of the bottles as accurate as possible, the hand blower familiarizes himself with the weights of the bottles as he blows them and can at once adjust any tendencies toward overweight or underweight. In the Wage Scale and Working Rules of the Glass Bottle Blowers' Association the blower is continually cautioned to "work as close to weight given as possible." Similar precautions are taken in blowing bottles by the machine process. For the past 30 years at least (1) (6),[1] the National Glass Bottle and Vial Manufacturers' Association, composed of manufacturers, and the Glass Bottle Blowers' Association, composed of blowers, have held annual conventions, where questions pertaining to their several interests are discussed and agreements made by which each party should be governed. The limit of variation in weights which would be permitted during the ensuing year has been one of the questions decided at these meetings. This point became of special importance after the passage of the Net Weight Amendment to the Federal Food and Drugs Act, March 3, 1913, when the food officials were also consulted. The variations agreed upon and adopted in 1914 have been readopted annually without change. The manufacturer has the privilege of rejecting bottles whose weights fall outside these allowable variations. They are used in this bulletin in calculating the maximum variation in the volume of bottled foods.

To show the extent to which any allowable variation will be applicable to all bottles, it is necessary to note that the variation in the weight of hand-blown bottles is greater than that of machine-blown bottles. While this is generally an accepted fact (7), it has been further verified by 27 sets of data collected in the course of these investigations, each containing measurements on 25 to 50 bottles of 4, 8, and 12 ounce weights. It was found that the respective average deviations were 0.12, 0.24, and 0.37 ounce in hand-blown ware, and 0.03, 0.06, and 0.18 ounce in machine-blown ware. It is pertinent also to note that machine manufacture has had a steady growth. In 1912 (2) 33 factories in the United States were equipped with bottle-blowing machines. In 1913 (2) 37 factories and in 1914 (5) 54 factories, or 37 per cent of those in the United States, were so equipped. It has been estimated that 45 per cent of the bottles blown in 1917 (7, p. 129) and 60 per cent of those blown in 1918[2] were made by automatic machines. This steady growth, together with the fact

[1] Figures in parentheses throughout this bulletin refer to the bibliography on page 20.
[2] Bureau of Chemistry surveys, unpublished.

that machine patents are now expiring, emphasizes the necessity for giving consideration to the smaller variations which may occur in machine-blown bottles.

BOTTLE FILLING.

The accuracy in bottle filling is affected by every operation of the bottler from the time he places his order for bottles until they are sealed and labeled. In placing the order the bottler has in mind, and sometimes states in his contract, the capacity which he desires. Upon receipt of the bottles the correctness of their capacity is ascertained by actual measurement, or else it is assumed that the manufacturer has delivered bottles having the capacity designated in the contract. According to the tests made the bottles are rejected or suitable arrangements are made for their use with respect to a proper declaration of quantity of contents. In a survey it was found that 10 of 16 bottling factories made tests on every lot of bottles received from the factories, and also that 10 of these bottlers did not specify in their contracts with the glass factories the capacities which they desired for their bottles. The transparent nature of the bottle compels the bottler to cater to a popular demand that the packages be reasonably full, which requires filling to a somewhat uniform height, leaving sufficient head space.

The liquid food is filled into the bottle by machines of various degrees of complexity. A general study of the catalogues of bottle-filler manufacturers has shown these fillers to fall into three general types. The first is practically a hand filler. It is equipped with a filling nozzle and a lever cut-off operated by hand. When bottles are filled to the desired filling point, as estimated by the eye or by comparison with a properly filled sample, the flow is cut off and the bottle corked. This type represents the simplest method of filling. The second type of filler works upon the siphon principle. The bottle is filled from a siphon tube connected with a constant level tank. As soon as the liquid in the bottle has reached the level of the liquid in the tank the flow ceases. The height of fill is adjusted by raising or lowering either the bottle or the delivery tube. The third type is a development of the second type in which the liquid runs into a measuring chamber of adjustable dimensions before delivery to the bottle. A uniform volume is thereby delivered into each bottle.

Of these types of fillers the second is most common. The third is used more generally for filling cans which are not transparent. Regardless of the type of machine used, the bottler is impelled to fill his bottles to a definite height in order that they may make a satisfactory appearance as a commercial article. It was found during the inspection of a number of factories that even where machines which measured the quantity to be delivered were used, continual

attention was given to the height of fill of the bottle. The short-capacity bottles, which were always too full and filled high in the neck, were partially emptied into the over-capacity bottles, which were not full enough, in order to obtain a more uniform quantity of contents.

FIG. 1.—Long-necked bottles.

It is the custom of bottlers to label their products with the quantity of contents either by a paper label or by having the statement blown into the bottle. In each case the bottler must depend upon the uniformity of the bottle to secure accurate statements of the quantity of contents. This fact is considered in this bulletin in calculating the variation in volume of bottled foods.

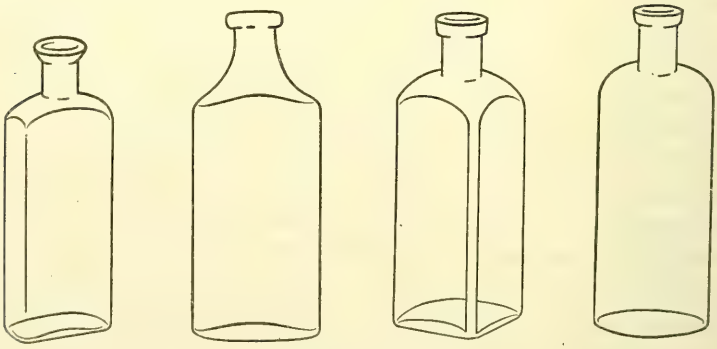

FIG. 2.—Short-necked bottles.

TYPES OF BOTTLES.

Although foods are put up in a large variety of bottles, three surveys of the industry indicate that certain types are very prevalent. In view of the mooted questions concerning the panel bottle it has not been included in this study. Figures 1 and 2 illustrate the types which have been studied. The cross section of the bottle may be

round, square, or oval, and the necks long and conical or cylindrical, or short and cylindrical. The type of shoulder shown in these figures, while of minor significance in some cases, is important in others and illustrates the type to which the data reported in this bulletin apply. It is intended that the results be applicable to the simplest and most prevalent types of bottles used for food purposes.

"GOOD COMMERCIAL PRACTICE" IN BOTTLING.

In considering the specifications which should be met by a commercial practice considered to be "good," the demands of the consumer and the law, as well as the ability of the bottler to meet the requirements, have been taken into account. Because of the transparency of the bottle, the bottler attempts to cater to the demands of the consumer that the bottle be as full as practicable, considering the necessary head space. When the bottler receives a shipment of bottles which are over capacity, he hesitates to fill the bottles with a larger quantity without changing the quantity of contents declaration on the label. On the other hand, when bottles which are under capacity are received the law demands that the contents declaration be changed to make the statement correct. If the true capacity of the bottle to the usual filling point differs only slightly from that desired, there is a possibility of making a slight increase or decrease in the height of fill. This change in the height of fill necessitates instructing a number of employees who have been trained to fill to a certain height. It also requires a change in the setting of filling machines if such are used. A further inconvenience is suffered by the necessity for the determination of the proper height of fill. A material change in height of fill, therefore, can be regarded only as a temporary expedient. It will be suffered by the manufacturer only long enough to permit him to give proper instructions to the bottle manufacturer from whom he makes his purchases. While readjustments are taking place, it is not considered that the bottler has yet attained conditions of good commercial practice.

It is evident that the first step of the bottler in eliminating his difficulties with respect to the variation in capacity of the bottles he receives is to make definite specifications in his orders. The law requires that the quantity of liquids shall be declared by volume. The height to which the bottler fills his bottles can be varied slightly, but to meet the demands of the law and the public he is required to demand of the bottle manufacturer a bottle with a definite capacity at a height of fill which will satisfy the public. This condition can be attained by inserting in the specifications in his orders the requirement that the bottle have a specified capacity at a definite height of fill. This is considered the first condition of good commercial practice.

When any lot of bottles is received, the best practice demands that they be tested. The test to be applied is whether they meet the specification as to capacity at the height of fill specified in the contract. If the bottles do not test correctly, two alternatives are possible. The bottles may be rejected or temporary expedients, such as changing the contents declaration on the labels, may be employed to use up the particular lot. Rejection of bottles involves the inconvenience of temporary loss of packages and friction with the manufacturer. It is for the bottler to decide which method will be employed. If the variation is excessive, good commercial practice would demand that they be rejected. Testing the capacity of a representative sample of each lot of bottles received and rejecting those lots with excessive variations from the contract specifications is the second step in the attainment of good commercial practice.

The testing of the bottles gives the bottler information as to his correct filling point. Whether or not the tests show a variation from his usual filling point wide enough to justify him in instructing his employees as to proper changes is a question for him to decide. The best practice would demand that the question of change of height of fill be given due consideration. The adoption of the process of making slight changes in the height of fill as indicated by the tests made on the various lots of bottles as received is the third step in the attainment of good commercial practice.

Printing labels with the quantity of contents before they are attached to the bottles is decidedly convenient. By making this statement beforehand the bottler determines the quantity of contents which he expects to fill into his bottles. The statement of quantity of contents is necessarily the same as that specified in his contract with the bottle manufacturer. The expediting of his business demands that labels be ordered before the bottles are received. There is always a possibility of altering the statement of quantity of contents by rubber stamp or by reprinting, but this is an inconvenience which will be suffered by the bottler only long enough to permit him to give proper instructions to his manufacturer to correct the capacity in the subsequent shipments. The application of labels bearing a definite, correct statement of the quantity of contents is regarded as the fourth step in the attainment of good commercial practice.

The development of good commercial practice is a growth and requires a sufficient amount of time for adjustment to proper conditions by the bottler. It involves the ordering of labels previous to the time bottles are ordered, and a requirement on the part of the bottler that his bottles be delivered to him as specified. Though this is an ideal condition and it is not conceivable that it could be continued without an occasional interruption, many factories are using this practice closely. For the purpose of this bulletin, therefore, good commercial

practice in bottling foods is the attainment of conditions in the bottler's state of business in which he (*a*) includes in his orders for bottles the specifications as to capacity when filled to a specified height, (*b*) tests a representative sample of every lot of bottles received, and rejects those lots appreciably under capacity, (*c*) fills his bottles to a height determined from the results of his tests, and (*d*) has his labels printed with a definite, correct statement as to the quantity of contents and applies them unaltered to the bottles he fills, such statement to be correct within his required variations.

The calculated maximum variations computed in this bulletin are based on the assumption that this specified good commercial practice in bottling has been attained.

CALCULATED MAXIMUM VARIATION IN THE VOLUME OF BOTTLED FOODS.

The first and most important requisite in the carrying out of the good commercial practice plan in bottling is that the variation in the bottles shall be as small as commercially practicable. With the use of accurate bottles the bottler is able to adjust his filling process to any extent he desires and to produce bottles of food which, in quantity of contents, vary within limits as narrow as he may wish to have them.

The calculated maximum variation in the volume of bottled foods is computed in this bulletin on the basis of the usual variations in the bottles. It is defined as the volume which is equivalent to the allowed weight variation of the bottle as manufactured.

Variations in the weight of bottles which the manufacturer shall allow to the blower, as published in the Wage Scale and Working Rules of the Glass Bottle Blowers' Association, are given in Table 1.

TABLE 1.—*Variations in weight of bottles allowed by manufacturers.*

Weight of bottles.	Under.	Over.
Ounces.	*Ounces.*	*Ounces.*
½ and under	⅛	⅛
[1] ½ to 1	⅛	¼
1 to 2	¼	¼
2 to 4	¼	½
4 to 6	⅜	⅝
6 to 8	½	¾
8 to 10	½	¾
10 to 12	¾	¾
12 to 14	1	1
14 to 17	1	1
17 to 20	1	1½
20 to 25	1¼	1½
25 to 28	1½	1½
28 to 32	1½	2
32 to 40	2	3
40 to 50	3	4
50 to 60	4	5

[1] Inclusive. The following figures are not inclusive.

The variations as given in Table 1 are applicable to bottles of particular weights. While bottles of any capacity may be blown at any specified weight, if so ordered, the general practice is to follow the weights and capacities stated in the Wage Scale and Working Rules of the Glass Bottle Blowers' Association. Weights of bottles of various capacities as stated in the Wage Scale and Working Rules have been compiled in Table 2.

TABLE 2.—*Weights of bottles of various capacities.*[1]

Types of bottles.	Capacity (fluid ounces)—										
	½	1	2	4	6	8	12	16	24	32	64
	Oz.[2]	*Oz.*[2]	*Oz.*[2]	*Oz.*[2]	*Oz.*[2]	*Oz.*[2]	*Oz.*[2]	*Oz.*[2]	*Oz.*[2]	*Oz.*[2]	*Oz.*[2]
Round and fluted prescriptions	1.25	1.50	2.0	3.5	5.0	6.5	9.0	11.0	15	18	.....
Round castor oils, lemon sirups, olive oils, etc	1.00	1.50	2.25 2.5	4.0	5.0	6.5	9.5	11.0	16	20	.....
Ovals, French squares, tall blakes, and oblongs	.75	1.25	2.0	4.0	5.5	7.0	10.0	12.0	18	20	.....
Flats, short blakes, and oblongs	1.00	1.50	2.5	4.5	6.0	8.0	11.0	14.0	18	22	.....
Grape juices and catsups, champagnes, octagons, rounds, squares	.....	1.50	2.25	4.0	5.5	6.5	10.0	13.0	19	22	34
Tinctures, round and square	.75	1.25	2.0	4.0	5.0	6.5	9.0	11.5	15	18	32
Range in weight	.75– 1.25	1.25– 1.50	2.0– 2.5	3.5– 4.5	5.0– 6.0	6.5– 8.0	9.0– 11.0	11.0– 14.0	15– 19	18– 22	32– 34
Corresponding range in Table 1	½–2	1–2	2–4	4–6	4–6	6–8	8–12	12–14	14–17	17–25	32–40

[1] Compiled from text of Wage Scale and Working Rules of the Glass Bottle Blowers' Association, 1918–19.
[2] Avoirdupois.

The simple types of bottles listed in Table 2 are very common food containers. They are the types to which the results found in this bulletin are applicable. The weights of bottles of any given capacity are so uniform that they fall within one of the definite ranges in weight mentioned in Table 1. Each range in weight corresponds to a capacity. For example, a corresponding range in Table 1 of 1 to 2 ounces, avoirdupois, corresponds to a capacity in fluid ounces of 1. Therefore, there is an allowed variation in weight which corresponds to each capacity, that is, the first column of Table 1 has been converted from terms of weight to terms of capacity.

An increase in the weight of the bottle is caused by the use of more glass, which thickens the walls and decreases the capacity. Since the bottler is penalized for short capacity, the overweight limits as given in Table 1 were selected as the basis of computing the maximum variations in capacity. The overweight limits have been computed to volume equivalents by use of the factor, 1 ounce of glass is equivalent to 3.1 drams in volume, the usual factor used by glass blowers and manufacturers.[3] This factor has been further verified by measurements and computations based on the specific gravity of

[3] Bureau of Chemistry Hearing of Glass Bottle Blowers' Association, May, 1913.

glass given in literature, and is found to be sufficiently accurate for use in this bulletin. The volumes equivalent to the variations in overweight as given in Table 1 are computed by this factor and tabulated in Table 9 (page 20) under the heading "Individual bottles," opposite the various capacities given in Table 2. These are calculated maximum variations computed in this bulletin, on which further computations are based in Tables 4 and 6.

The blower is continually cautioned to "work as close to the weight specified as possible." Since those bottles which are outside the permitted variations in weight may be rejected, the blower will attempt to have them occur as seldom as possible. As a result of following this caution and attempting to keep within the limit, the weights of the bottles will be distributed in accordance with the normal law of errors. For example, if the blower intends to deliver a bottle weighing 8 ounces, most of his bottles will weigh close to 8 ounces and only a few will be over or under by large amounts. Their average weight will approximate 8 ounces and there will be about as many over as under weight. The allowable variations stated in Table 1 would probably occur very few times in the course of a day's work. These are the primary conditions for distribution according to the normal law of errors. In accordance with the principles of the law of errors, the variation of the average of the representative sample, which has the same chance of occurrence as the variation of an individual bottle, is equivalent to the individual variation divided by the square root of the number of bottles in the sample (3). In making observations of this type, it has been found that at least 50 bottles should be measured in order that the results may be accurately representative. The calculated maximum variation in the volume of a representative sample has been computed according to this rule and included in Table 9 under the column "Average of representative sample."

Data to show the possibilities of meeting these variations of the average volume are not presented in this bulletin. Studies of a similar nature (4) on other products have shown that variations computed by this method are within the range of commercial possibilities.

In the calculations of the maximum variations in Table 9 the assumption has been made that the bottler is able to limit his variations in filling to any desired degree. The figures chosen for the calculations are the weight variations allowed to hand blowers. Machine-blown bottles are more uniform in weight and also in capacity. Since the majority of the bottles are blown by machine, this calculated maximum variation is representative of the variations in the volume of bottle foods when they are packed under the specific good commercial practice conditions outlined, which require that the bottler give special attention to his methods of filling. Data are presented to show the possibilities of meeting the calculated maximum variations.

EXPERIMENTAL RESULTS.

The data which have been collected were taken for the purpose of showing the chance of occurrence of the calculated maximum variations in the capacity of the bottle and in the quantity of food therein. Other data were also collected to show the possibilities of meeting the calculated maximum variations by such temporary expedients as changing the height of fill or the declaration on the label.

VARIATION IN CAPACITY OF BOTTLES.

In order to determine the variations due exclusively to difference in the capacity of bottles, 22 representative glass factories located in Virginia, Maryland, Pennsylvania, New Jersey, West Virginia, and Ohio were visited, and 28 sets of measurements, including 1,090 bottles blown by hand and by machine processes, were taken. Certain conditions of blowing were prescribed before a set of bottles was selected for measurement. The moulds were noted to be in good repair and to have been in use at least one hour before the bottles selected for measurement were blown. It was stated that the glass was in good workable condition. All machines were operating under favorable circumstances and all blowers and gatherers were journeymen workmen. In the case of hand-blown bottles, measurements were made on a set which had been blown in a single mould. In the case of machine-blown bottles, a run of machine ware was measured. All measurements were made by pouring water from a standardized graduate into the bottles. A recapitulation of the results obtained is given in Table 3.

TABLE 3.—*Variations in capacity of bottles.*

[Data based on measurements in glass factories.]

Reference No.	Size of bottle.	Type.	Number measured.	Capacity at top.			Average deviation.	Average of average deviations of the size.
				Maximum.	Minimum.	Average.		
		HAND BLOWN.						
	Fl. oz.			*Fl. oz.*	*Fl. oz.*	*Fl. oz.*	*Fl. oz.*	*Fl. oz.*
1006-0	1	Shoo-fly flask	25	1.08	0.93	1.03	0.035	.....
1006-1	1	do	25	1.03	.90	.96	.032	0.033
1002-B	3	Oval prescription	25	3.55	3.31	3.47	.042	.....
1002-S	3	do	25	3.31	3.11	3.21	.039	.....
1010-1	3	do	25	3.21	2.99	3.11	.066	.....
1010-2	3	do	25	3.18	2.91	3.00	.055	.....
1001	4	Round square	50	4.77	4.33	4.52	.099	.....
1006-1	4	Shoo-fly flask	25	4.22	3.92	4.07	.074	.....
1006-2	4	do	25	4.29	3.89	4.12	.080	.....
1008	4	Oval prescription	50	4.66	4.19	4.48	.071	.068
1001	8	do	50	9.06	8.08	8.69	.15	.....
1002	8	Tall blake	50	9.19	8.25	8.62	.13	.....
1005	8	Soda water	50	8.92	7.67	8.32	.21	.16
1005	12	Beer	50	13.58	12.71	13.18	.15	.15
1000-K	24	Brandy	25	24.84	23.49	24.24	.30	.....
1000-P	24	do	25	25.69	24.17	24.71	.36	.33
1005	64	Round packer	15	68.48	66.46	67.30	.41	.41

TABLE 3.—*Variations in capacity of bottles*—Continued.

Reference No.	Size of bottle.	Type.	Number measured.	Capacity at top.			Average deviation.	Average of average deviations of the size.
				Maximum.	Minimum.	Average.		
		MACHINE BLOWN.						
	Fl. oz.			*Fl. oz.*	*Fl. oz.*	*Fl. oz.*	*Fl. oz.*	*Fl. oz.*
1004-M	2	Round packer	50	2.44	2.37	2.40	0.013	.....
1004-1	2	.....do	50	2.44	2.37	2.40	.012	.....
1004-2	2	.....do	50	2.42	2.37	2.40	.011	0.012
1004	4	Prescription	50	5.75	5.44	5.57	.068	.068
1015-A	8	Catsup	50	8.15	7.81	8.05	.06	.....
1015-B	8	Grape juice	50	8.69	8.48	8.57	.04	.....
1004	8	Oval prescription	50	9.02	8.72	8.86	.07	.....
1014	8	.....do	50	8.82	8.52	8.72	.04	.05
1004	12	.....do	50	10.75	10.48	10.65	.05	.05
1004-U	16	.....do	50	17.17	16.70	16.97	.09	.....
1004-W	16	.....do	25	17.58	17.31	17.47	.05	.07

Measurements were taken on a variety of types of bottles, the number measured in every set was usually 25 or 50, and several sets of data were usually collected on one size of bottles. The maximum, minimum, and average capacities to the tops of the bottles show the usual range of capacities. The average deviation is the average of all the variations from the average capacity of the set as measured. The average of the average deviation of the various sizes, as shown in the last column, is an index of the variation of the bottles of the size mentioned. The figures in this column are used to compute the chance of occurrence of the calculated maximum variation in the capacity of bottled foods.

The chances of occurrence of variations in a normal frequency distribution are calculated in accordance with the laws of probability as found in standard textbooks (3). The probability of occurrence of a given variation is found by the formula $f=\frac{x}{r}$, where f is a factor whose probability value is read from a table of probability integrals, x is the limiting variation whose probability of occurrence is desired, and r is the probable error of a single observation of the distribution. The complement of the equivalent of f gives the probability that variations greater than x will occur, and the resulting fraction, reduced until its numerator is one, gives the chances of their occurrence.

The variation for which it is desired to determine the chance of occurrence is the calculated maximum variation given in Table 9. This figure is given in Table 4 in the column headed "x." The probable error as found experimentally is computed from the last column of Table 3. For practical purposes, the probable error is equivalent to 0.8453 times the average deviation. It is so computed and included in Table 4, under the column headed "r." The remaining

computations in Table 4 have been made according to the method outlined in the preceding paragraph.

TABLE 4.—*Chances of occurrence of variations in the capacity of bottles larger than the calculated maximum variations.*

HAND-BLOWN.

Capacity.	Calculated maximum variation, individual bottles. (x)	Average deviation × 0.8453. (r)	$\frac{x}{r}$ (f)	Probability.	Chance of occurrence based on observed data.
Fluid oz.	*Fluid oz.*				1 in:
1	0.10	0.028	3.58	0.9842	63
4	.24	.057	4.21	.9955	222
8	.29	.135	2.15	.8530	7
12	.29	.127	2.28	.8759	8
24	.39	.279	1.40	.6550	3
64	1.16	.346	3.36	.9766	43

MACHINE-BLOWN.

2	0.19	0.010	19.00	.9999+	over 10,000
4	.24	.057	4.21	.9955	222
8	.29	.042	6.90	.9999+	over 10,000
12	.29	.042	6.90	.9999+	over 10,000
16	.39	.059	6.62	.9999+	over 10,000

While the chances of occurrence of the calculated maximum variation, 1 in 7, 1 in 8, and 1 in 3, as shown for the hand-blown 8, 12, and 24 ounce sizes, respectively, are not very large, at least the table shows that they are far from even, and indicates that there is not an unreasonable possibility that hand blowers may meet the required calculated maximum variations, in a large percentage of cases. It is also possible that further data on other types of 8 and 12 ounce hand-blown bottles might reduce the chance of occurrence of the calculated maximum variation, since these sizes include soda water and beer bottles, in which exceptional care as to exact weight is not exercised in blowing. The 24 ounce size is not exceptionally common, and a majority of the other two sizes are blown by machine.

The averages of the figures in the last column of Table 4 are 1 in 58 for hand-blown bottles and 1 in more than 10,000 for machine-blown bottles. These figures show the reliability of the calculated maximum variations when used as limits of variation in the capacity of bottles. In view of the relative prevalence of machine-blown bottles and the possibilities of exceptional care in blowing hand-blown bottles, the data indicate that only a small percentage of the bottles as they occur on the market should vary in capacity by more than the calculated maximum variations.

VARIATION IN VOLUME OF BOTTLED FOODS.

In order to determine the variation in volume of the food filled into the bottle, 27 bottling establishments located at various points

in Virginia, West Virginia, and Maryland were visited, and 20 sets of measurements, including 524 bottles, were taken. Rough measurements were first made on the bottles being used, from the result of which the bottler was given an aim in ounces by which to fill 50 bottles for measurement. The aim given was as consistent as possible with his declaration of the quantity of contents, but slight changes were often made, even though he were approximately following the good commercial practice outlined in this bulletin. The bottler was then requested to fill a number of his bottles with the specified number of ounces given to him as an aim, take the average of the distance from the top, and adjust his filling machine or filling system to fill to this average height. In cases where allowance for contraction due to change in temperature was necessary, he was instructed to deliver bottles which would be filled to this aim when cool. In cases where the bottles could not be opened, such as soda water, 50 empty bottles were selected at random, paired with full bottles, and filled to the same height by pouring water from a standardized graduate. The results so obtained were assumed to be equivalent to the volumes of food contained in the original bottles.

The results obtained are recapitulated in Table 5.

TABLE 5.—*Variation in volume of foods packed in bottles.*

Reference No.	Product.	Type of bottle.			Number measured.	Aim.	Volume found.			Average deviation.	Average of average deviations.	Average minus aim.	Average of average minus aim.
		Manufactured.	Base.	Neck.			Maximum.	Minimum.	Average.				
						Fl. oz.	*Fl. oz.*	*Fl. oz.*	*Fl. oz.*	*Fl. oz.*	*Fl. oz.*	*Fl. oz.*	*Fl. oz.*
1120	Flavoring extract.	H	Sq.	Con	25	0.75	0.88	0.66	0.76	0.034	0.034	0.01	0.01
1100	Soda water	H	Rd.	Con	50	6.0	7.84	5.44	6.38	.29	.....	.39	.....
1110	Coca cola	M	Sq.	Con	25	6.0	6.42	4.97	5.87	.27	.....	−.12	.....
1111	do	M	Sq.	Con	25	6.0	6.25	4.66	5.66	.25	.27	−.34	− .02
1105	do	H	Rd.	Con	50	7.0	7.54	6.42	7.07	.22	.....	.07	.....
1108	Soda water	.....	Rd.	Cyl	50	7.0	8.18	6.12	7.34	.37	.....	.34	.....
1109	do	H	Rd.	Con	50	7.0	7.77	6.56	7.01	.24	.....	−.02	.....
1113	do	.....	Rd.	Con	25	7.5	8.69	6.15	7.28	.63	.....	−.22	.....
1101	do	H	Rd.	Con	50	8.0	8.38	7.54	7.97	.15	.32	−.03	.04
1114	Vinegar	H	Sq.	Con	10	15.0	15.68	14.94	15.51	.15	.15	.51	.51
1115	do	H	Rd.	Cyl. jar	10	20.0	20.45	18.93	19.77	.34	.....	−.22	.....
1116	do	H	Rd.	Cyl. jar	10	25.0	26.20	25.01	25.62	.27	.....	.63	.....
1124	do	H	Rd.	Cyl. jar	20	25.5	26.70	25.52	26.30	.19	.....	.82	.....
1104	do	M	Rd.	Cyl. jar	20	26.0	26.87	25.69	26.29	.31	.28	.30	.38
1103	do	M	Rd.	Cyl	25	63.0	63.75	62.91	63.25	.19	.....	.25	.....
1117	do	H	Rd.	Cyl. jug	10	63.0	65.61	63.75	64.25	.37	.....	1.25	.....
1123	do	H	Rd.	Cyl. jug	19	63.0	63.24	61.22	62.22	.39	.32	−.78	.24
1102	do	M	Rd.	Cyl. jug	20	128.0	130.70	126.82	128.02	.93	.....	.01	.....
1118	do	H	Rd.	Cyl. jug	10	128.0	128.51	125.46	127.27	1.03	.....	.74	.....
1122	do	H	Rd.	Cyl. jug	20	129.0	129.69	126.31	127.34	.47	.81	−1.67	− .80

With the exception of one set of data, measurements were taken on bottles of soda water and vinegar, and data were taken on hand-blown and machine-blown bottles, round and square bottles, bottles with conical and cylindrical necks, jars, and jugs. Some of these

sets were filled by hand and some by machine. The maximum, minimum, and average volumes show the range of volume. As in Table 3, the average of the average deviations of various sizes is an index of the variation in volume of food in the bottles of the size mentioned, and the figures in this column are used to compute the chance of occurrence of the calculated maximum variations in the volume of bottled foods. By computations similar to those used in Table 4, the chance of occurrence of variations in the volume of food in the bottle larger than the calculated maximum variations has been computed and compiled in Table 6.

TABLE 6.—*Chances of occurrence of variations in the volume of food in the bottles larger than the calculated maximum variations.*

Capacity.	Calculated maximum variation, individual bottles.	Average deviation ×0.8453.	$\frac{x}{r}$	Probability.	Chance of occurrence based on observed data.
	(x)	(r)	(f)		
Fl. oz.	*Fl. oz.*	*Fl. oz.*			1 in—
0.75	0.10	0.029	3.45	0.9800	50
6	.24	.227	1.06	.5254	2
8	.29	.272	1.07	.5295	2
15	.39	.131	2.98	.9556	23
20–26	.39	.236	1.65	.7342	4
63	1.16	.269	4.31	.9964	278
128	1.94	.686	2.83	.9437	18

The results of the calculations in Table 6 are given in the last column. The average of the last column is 54, showing that, as a rule, one bottle in 54 will fall without the calculated maximum variation. With the exception of the 63-ounce size, where the chance of occurrence of the calculated maximum is 1 in 278, the results indicate that there might be a frequent occurrence of variations larger than the calculated maximum variation. It should be noted, however, that soda water is perhaps the most difficult food to bottle accurately, since it is carbonated. The vinegar bottled in the establishments in which these data were collected was bottled hot, thereby giving chances for additional variation due to cooling. When it is considered that the aim of the bottler was changed in some cases from his normal height of fill, it is evident that a number of factors have been introduced to cause variation which would not be met in bottling uncarbonated liquids under conditions which have been customary for some time, as would be the case if the bottler were following the good commercial practice outlined in this bulletin. These data represent variations which would be met under very extreme and difficult conditions. Under more favorable circumstances the chances of occurrence as calculated in Table 6 would be reduced.

The average deviations given in Tables 4 and 6 afford a comparison of variations in the capacities of the bottles and variations in volume of food after filling. The deviations are compiled in Table 7 for comparison.

TABLE 7.—*Comparison of the variation in capacities of bottles with the variation in volume of the bottled food.*

Capacity of bottles.	Average of average deviations in the capacity of hand-blown bottles.	Average of average deviations of the volume of food in the bottle.
Fluid oz.	*Fluid oz.*	*Fluid oz.*
0.75	----	0.034
1	0.033	----
4	.068	----
6	----	.269
8	.16	.322
12	.15	----
16	----	.155
24	.33	.279
64	.41	.318
128	----	.811

The average deviation in the capacities of the bottles of a given size is approximately equal to the average deviation of the volume of food contained in the bottles of that size. The fact that these two deviations are practically equivalent, supports the belief that the volume variation of bottled foods is approximately equivalent to the capacity variation of the bottles themselves when blown by hand. The calculated maximum variation apparently has about the same relation to the capacity of the bottle as to the volume of food in the bottle after it is filled.

In view of the unfavorable circumstances under which the data on the volume of bottled foods have been taken and the approximate agreement with the data on the variation in the capacity of bottles, the data indicate that only a small percentage of the bottled foods on the market should vary in quantity of contents more widely than the calculated maximum variations.

RELATION BETWEEN CALCULATED MAXIMUM VARIATION AND TEMPORARY METHODS OF MEETING DECLARED VOLUME.

The calculated maximum variation is not large enough to prevent the bottler from meeting it by the two temporary methods ordinarily used, namely, changing the height of fill or changing the declaration of the quantity of contents on the label.

In the course of the investigations, capacity measurements were made on bottles from the base of the shoulder to the usual aim in filling and to the top of the bottle. It is recognized that the base of the shoulder is not a definite filling point and that measurements

will vary widely. However, the best estimate possible was made to determine this point, after which the measurements on 50 bottles were averaged. The aim, determined by the manufacturer of the bottles, was the height to which he usually fills to make his tests as to capacity. A recapitulation of the data, showing the average capacity of the bottles measured and the capacity from the base of the shoulder to the top and from the aim to the top, with their relations to the calculated maximum variations, is given in Table 8.

TABLE 8.—*Average shoulder to top capacity and head space (bottles with cylindrical necks and conical necks).*

Size.	Reference No.	Type.	Number measured.	Calculated maximum deviation.	Volume (shoulder to top).	Calculated maximum (shoulder to top).	Volume (aim to top).	Calculated maximum (aim to top).
		CYLINDRICAL NECKS.						
Fl. oz.				*Fl. oz.*	*Fl. oz.*	*Ratio.*	*Fl. oz.*	*Ratio.*
1	1006–0	Shoo-fly flask	25		0.39	0.3	0.09	1.1
	1006–1	do	25	0.10	.35	.3	.08	1.2
		Average				.3		1.2
2	1004–M	Round packer	50		.47	.4	.17	1.1
	1004–1	do	50		.47	.4	.22	1.6
	1004–2	do	50	.19	.44	.4	.11	1.7
		Average				.4		1.5
3	1002–B	Oval prescription	25		.45	.5	.33	.7
	1002–S	do	25		.37	.6	.30	.8
	1010–1	do	25		.61	.4	.21	1.1
	1010–2	do	25		.60	.4	.38	1.3
4	1001	Round square	50		.71	.3	.38	.6
	1008	Oval prescription	50		.55	.4	.16	1.5
	1004	do	50	.24	1.42	.2	.63	.4
		Average				.4		.9
8	1001	Oval prescription	50		1.19	.2	.71	.4
	1002	Blake	50		1.05	.3	.44	.7
	1004	Oval prescription	50		1.38	.2	.36	.8
	1014	do	50	.29	1.52	.2	.65	.4
		Average				.2		.6
10–12	1004	Oval prescription	50	.29	1.57	.2	.24	1.2
		Average				.2		1.2
16	1004	Oval prescription	50		2.86	.1	.36	1.1
	1004	do	25	.39	2.51	.2	.27	1.4
		Average				.2		1.3
64	1005	Round packer	15	1.61	10.65	.1	4.39	.3
		Average				.1		.3
		Grand average of individual observations.				.30		.97
		CONICAL NECK.						
4	1006–1	Shoo-fly flask	25		1.30	.2	.20	1.2
	1006–2	do	25	.24	1.35	.2	.23	1.0
		Average				.2		1.1
8	1005	Soda	50		1.87	.2	.66	.4
	1015–A	Catsup	50		2.68	.1	.19	1.5
	1015–B	Grape juice	50	.29	3.03	.1	.55	.5
		Average				.1		.8
12	1005	Beer	50	.29	3.15	.1	.78	.4
24	1000–K	Brandy	25		6.68	.6	.72	.5
	1000–P	do	25	.39	6.86	.6	.66	.6
		Average				.6		.6
		Grand average of individual observations				.23		.76

The calculated maximum variations average nearly 0.3 of the available space from the base of the shoulder to the top in cylindrical-neck bottles and nearly 0.3 in conical-neck bottles; that is, the bottler has about three times enough room in his filling range to adjust his

height of fill to meet the variations equivalent to the calculated maximum variations. The calculated maximum variations average about the same as the space in the bottle from the aim to the top, in the case of cylindrical-neck bottles and 0.8 in the conical-neck bottles (Table 8). Accordingly there is sufficient room in the bottles to permit changes from the usual height of fill to the limits of the calculated maximum variations.

The unit of change in declaration is of concern to the bottler when he receives bottles short of the capacity which he expects. It is the custom to declare the quantity of contents on bottled foods in whole units. In a survey of the bottling of flavoring extracts and similar products it was found that the prevalent sizes of bottles were 1, 2, 4, 8, and 12 ounces, 1 pint, 1 quart, ½ gallon, and 1 gallon. In bottles containing less than 2 ounces some of the declarations varied by ⅛-ounce units; in sizes from 2 to 8 ounces, some of the declarations varied by ¼-ounce units; and in sizes above 8 ounces, some varied by ½-ounce units. The calculated maximum variations for 2 ounce, 8 ounce, and 1 pint capacities are 0.19, 0.29, and 0.39 ounce, respectively, which are approximately equivalent to the usual units of declaration for these sizes of bottles. The bottler would therefore meet the variations equivalent to the calculated maximum variations if he made the usual changes in his units of declaration. It follows that the bottler's usual temporary methods of meeting the proper declared volume can be governed by the calculated maximum variations as found in this bulletin.

PRACTICAL APPLICATION OF RESULTS.

The bottler will be able to apply the results of this investigation as outlined in Table 9 to guide him in making tests on bottles received. If the capacities of the bottles at his usual filling point vary from the capacity ordered by amounts greater than the results given in Table 9, he will necessarily feel that some further steps should be taken to meet properly the requirements of the law that the volume of food declared on the labels be correct. The bottle manufacturer will be able to use the results in Table 9 to guide him in determining whether or not any shortage found in the volume of bottled food may be due to unavoidable difficulties in the manufacturing or filling of the bottles.

SUMMARY.

Good commercial practice in bottling foods has been considered in this bulletin to be the attainment of conditions in the bottler's state of business in which he (*a*) includes in his orders for bottles the specifications as to capacity when filled to a specified height,

(b) tests representative samples of every lot of bottles received, rejecting those appreciably under capacity, (*c*) fills his bottles to a height determined from the results of his tests, and (*d*) has his labels printed with a definite, correct statement of the quantity of contents and applies them unaltered.

The calculated maximum variations in the volume of bottled foods, as given in Table 9, have been computed from the weight variation allowed the blowers by the manufacturers, and by the use of the relation between the weight and volume of bottle glass.

TABLE 9.—*Calculated maximum variation in volume of bottled foods.*

Capacity of bottles.	Calculated maximum variation in volume.	
	Individual bottles.	Average of representative samples.
Fl. oz.	*Fl. oz.*	*Fl. oz.*
½	0.10	0.014
1	.10	.014
2	.19	.027
4	.24	.034
6	.24	.034
8	.29	.041
12	.29	.041
16	.39	.056
24	.39	.056
32	.58	.083
64	1.16	.17
128	1.94	.28

Data on the capacity of bottles and volume of food in bottles indicate that only a small percentage of the bottles of food filled in accordance with good commercial practice, as outlined in this bulletin, should vary in quantity of contents by more than the calculated maximum variations.

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BULLETIN No. 1010

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WM. A. TAYLOR, Chief

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THE PREPARATION OF AN EDIBLE OIL FROM CRUDE CORN OIL.

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SCOPE OF THE INVESTIGATIONS.

In a study made in 1919 of the production of corn oil in the United States,[1] in the course of which special attention was given to the manufacture of corn products as practiced in the so-called hominy mills and in starch and glucose plants, the fact developed that although there were 22 plants in the country which produced corn oil, only four of these were equipped at that time for producing refined edible oil from the crude product. The four plants refined not only the oil produced in their own mills but also a large proportion of that produced by other operators. There is now, however, a tendency among the smaller operators to consider the feasibility of refining their own crude oil, and consequently interest has been manifested in the refining process.

As a general rule, vegetable oils are refined [2] by a process consisting of three main operations: (1) Neutralizing the free fatty acids and

[1] Sievers, A. F. The production and utilization of corn oil in the United States. U. S. Dept. Agr. Bul. 904, 23 p., 11 fig. 1920.

[2] The term "refining" as used in this bulletin refers to the complete process of purification of the oil and not to the alkali treatment only, in which sense it is frequently used.

removing the albuminous and coloring matter by treating the oil with caustic;[3] (2) bleaching the oil by heating with fuller's earth or decolorizing carbons, or both; and (3) deodorizing the oil by treating it with steam under reduced pressure at a high temperature, which also effects a further bleaching.

This general procedure is followed, in the main, by most refiners of corn oil, but considerable difference of opinion exists regarding the technical details of the process. Consequently, it was thought advisable to make a thorough study of the preparation of an edible oil from the crude product with a view to clarifying some of the details in dispute.

This bulletin includes a discussion of experiments on the refining of corn oil under various modifications of the usual methods, a comparison of the economics of the methods proposed, and detailed plans of a commercial refining plant.

SMALL-QUANTITY EXPERIMENTS ON METHODS OF REFINING CORN OIL.

TREATMENT WITH CAUSTIC.

The technique involved in treating an oil with alkali varies according to the character of the oil and the individual opinion and experience of the operator. Oil obtained from the average quality of corn germs does not as a rule contain much more than 2 per cent of free fatty acids, and in many cases its acidity is as low as 1 per cent. If a good grade of corn is used the oil produced varies but slightly during the season with regard to acidity and color. It is possible, therefore, to refine many batches of such an oil with only slight, if any, changes in the process.

The oil used for the experimental work herein described was produced in a hominy mill and contained 1.76 per cent of free fatty acids. Method 1 was the so-called official method[4] used in control laboratories for grading cottonseed oils except that the maximum temperature was 55° C. instead of 45° C. In this method the quantity of caustic solution added is equal to 10 per cent of the weight of the oil. In method 2 only sufficient caustic solution is added to neutralize the free fatty acids present plus an additional quantity to remove the color and extraneous matter, the excess quantity being determined by the behavior of the oil under preliminary treatment. The experiments recorded are designed to show the proper strength of caustic to use with these two methods and, in the case of method 2, the quantity of excess which should be used, the two methods differing only in the quantity of caustic added. The technique employed in each case follows:

[3] The term "caustic" as used in this bulletin refers in all cases to sodium-hydroxid solution.

[4] Interstate Cottonseed Crushers' Association. Official methods adopted by the chemists' committee and rules committee. III. Crude cottonseed oil. *In* Cotton Oil Press, v. 3, no. 3, p. 117. 1919.

The oil is placed in a suitable container equipped with a mechanical stirrer and agitated constantly while the caustic solution is slowly added. After being stirred for five minutes, to insure a thorough mixing, the oil is gently heated to 55° C. over a 15-minute period. When the oil approaches this temperature it breaks.[5] The stirring is now stopped and the oil allowed to stand for three hours at a temperature of 50° to 55° C. After cooling, it is separated from the deposited soapstock. In the experiments in which small quantities were used in beakers, the refining losses were determined by pouring off the oil from the soapstock.

In the first experiments with method 1, caustic solutions of 10°, 12°, 14°, and 16° Bé. were used, while with method 2 the solutions used were of 5°, 10°, 14°, and 20° Bé. strength. In each case the test was made on 100 grams of oil. With method 2, 10 per cent of caustic in excess of the quantity necessary to neutralize the free fatty acids was used. The results are shown in Table 1.

TABLE 1.—*Results of treating corn oil with several concentrations of caustic in connection with methods 1 and 2.*

Method and number of experiment.	Strength of caustic used.	Refining loss.	Free fatty acids in treated oils.	Character of settling and condition of soapstock.
Method 1:	*° Bé.*	*Per cent.*	*Per cent.*	
1	16	8.47	0.033	Rapid settling; soapstock is light and flaky and occludes much oil.
2	14	5.7	.031	Soapstock very much like that in experiment 1, but appears to contain less oil.
3	12	5.0	.037	Soapstock forms a semiliquid layer which hardens to soft petrolatum consistency on cooling.
4	10	4.6	.047	
Method 2:				
5	20	27.5	.076	Soapstock very slimy and does not settle firmly.
6	14	11.7	.047	Settles more rapidly than in experiment 5; soapstock slides.
7	10	11.9	.026	
8	5	12.5	.056	Soapstock liquid when hot; does not harden entirely on cooling.

The soapstock obtained by the two methods differs greatly. That obtained by method 1 is in all cases semiliquid while warm, and on cooling hardens to a consistency like that of soft petrolatum. Such soapstock occludes very little oil, with attendant low refining losses. It appears that the weaker concentrations of caustic, such as 10° and 12° Bé., give better results on corn oil.

Method 2 results in very high refining losses, because the soapstock in practically all cases is very slimy and occludes much oil. Accordingly, the most suitable concentration to use is apparently a strength of 14° Bé. It is evident that with this method it is beneficial to add some material to harden the soapstock in order to reduce the refining losses.

The next series of experiments was for the purpose of determining the quantity of excess caustic that should be used in method 2. In all cases 1.5 per cent of soda ash was added after the break, in order to harden the soapstock. Caustic of a strength of 14° Bé. was used

[5] The appearance given to oil when coagulations of soap occur during refining.

in 10, 50, 100, and 200 per cent excess. Table 2 shows the results of these tests.

TABLE 2.—*Results of using 10, 50, 100, and 200 per cent excess of 14° Bé. caustic with method 2.*

Experiment.	Excess caustic used.	Quantity of soda ash.	Refining loss.	Free fatty acid after treatment.	Character of settling and condition of soapstock.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	
No. 15	10	1.5	9.0	0.051	Soapstock very soft and slimy.
No. 16	50	1.5	8.2	.041	Soapstock slightly more compact than that in experiment 15, but slides in mass.
No. 17	100	1.5	8.0	.033	Soapstock very much like that in experiment 16.
No. 18	200	1.5	7.2	.070	Soapstock very much like that in experiments 15 and 16.

The foregoing tests show that although not enough soda ash was used to make the soapstock firm it resulted in the soapstock settling to a much thinner layer, so that much less oil was occluded. A number of experiments were performed in which other dehydrating substances were used; namely, anhydrous sodium sulphate, calcium sulphate (plaster of Paris), and common salt. Of these substances only the dry sodium sulphate compared favorably with the commercial soda ash in the hardening effect upon the soapstock. Table 3 shows the effect of using larger quantities of soda ash in connection with method 2.

TABLE 3.—*Effect of the use of 2 and 3 per cent of soda ash on the soapstock in connection with method 2 under several conditions.*

Experiment.	Strength of caustic used.	Excess caustic used.	Quantity of soda ash used.	Refining loss— By pouring off the oil.	Refining loss— After heating and recooling soapstock.	Condition of soapstock.
	°*Bé.*	*Per cent.*	*Per cent.*			
No. 19	14	50	2	7.7	5.6	Firm.
No. 20	14	50	3	9.4	5.9	Do.
No. 21	14	100	2	6.7	5.4	Very firm.
No. 22	14	100	3	5.5	5.5	Do.
No. 23	14	200	2	7.3	5.9	Very firm and bulky.
No. 24	14	200	3	7.3	7.0	Do.

It will be seen from Table 3 that the refining loss can be very materially reduced by the use of 2 per cent of soda ash in connection with method 2, whether the excess caustic used is 50, 100, or 200 per cent. The use of an additional 1 per cent is of no advantage, because a greater bulk of soapstock results, with a consequent greater occlusion of oil. In all these tests the soapstock was firm and permitted the thorough draining off of the oil. It was found that when the

soapstock was heated to about 50° C. and rehardened by cooling, more oil separated out and could be drained off. In this way the refining losses were still further reduced.

So far as refining loss is concerned, method 1 with 10° Bé. caustic and method 2 with 14° Bé. caustic, using 50 per cent excess and 2 per cent soda ash, give satisfactory results. The oil resulting from either method is low in free fatty acids, but that from method 1 appears to bleach somewhat better when treated with fuller's earth and deodorized, which is due no doubt to the greater excess of caustic used.

After being treated by method 1 the oil is quite turbid, because of a fine suspension of moisture and soap. That soap is present is evidenced by the fact that dehydration, while it clarifies the oil, leaves fine particles in suspension, which gradually settle out on cooling. Therefore, oils treated by this method must be washed in order to remove the soap. The oil from method 2, although somewhat turbid, evidently does not contain soap, because when the moisture is removed the oil is absolutely clear.

BLEACHING.

Vegetable oils are usually bleached by means of fuller's earth or finely divided carbon. Oils differ greatly in the ease with which they can be bleached, corn oil being particularly difficult. In order to formulate an exact method for bleaching this oil by means of fuller's earth, several experiments were made to establish (1) the proportion of earth necessary, (2) the proper temperature, and (3) the proper length of treatment.

In the first experiment four samples of a composite of caustic-treated oils were used with 2, 4, 7, and 10 per cent of standard fuller's earth,[6] respectively. One hundred grams of oil were heated, with constant stirring, to 110° C. and kept at that temperature about 10 minutes to remove all traces of moisture. This treatment is considered necessary, because the earth does not effect a satisfactory bleach if the oil contains any moisture. The temperature was held at 105° C., while the earth was added slowly and the stirring continued for five minutes. The oil was then rapidly filtered on a force filter. Figure 1 shows the extent to which the several proportions of earth removed the color. The readings in all cases were made in a 2-inch cell with a Lovibond tintometer. The quantity of oil available in these preliminary experiments was not sufficient to enable the use of the 5¼-inch cell, which is considered the standard.

The results show, as was to be expected, that, within the range of this experiment, the bleaching increases with the increase in the per-

[6] Standard fuller's earth is recommended by the American Oil Chemists' Society for bleaching vegetable oils and may be obtained from the secretary of that society.

centage of earth used. Seven per cent of earth appears to be the most beneficial, but from a practical standpoint 5 or 6 per cent is sufficient, since no reduction in red is obtained with higher proportions. There is a limit, of course, to the proportion of earth which may be used in practice. The expense involved would not justify the use of more than 6 per cent. The expense lies not only in the cost

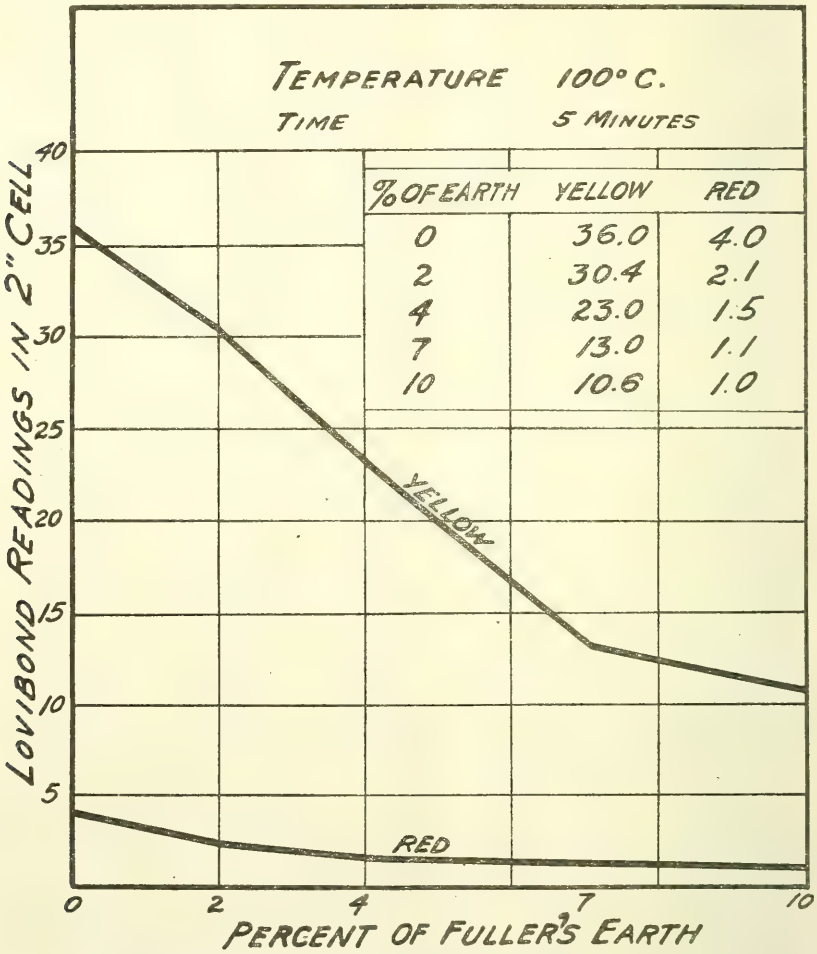

FIG. 1.—Relation between the proportion of fuller's earth used and the extent of the bleaching effected.

of the earth, but in the additional loss of oil which is entailed by the use of the greater quantities and the somewhat greater expense of filtering. Fuller's earth generally shows less bleaching efficiency when used in laboratory quantities than when used in large-scale operations. Hence, the use of a maximum of 5 or 6 per cent of earth, as generally practiced in refineries, would seem to be in accordance with the results of these tests.

Equally as important as the proportion of earth is the temperature; hence, experiments were made to determine the proper temperature range at which the oil should be treated. A sample of oil which had previously been dehydrated in the manner described was divided into five lots, each lot to be bleached with 6 per cent of fuller's earth

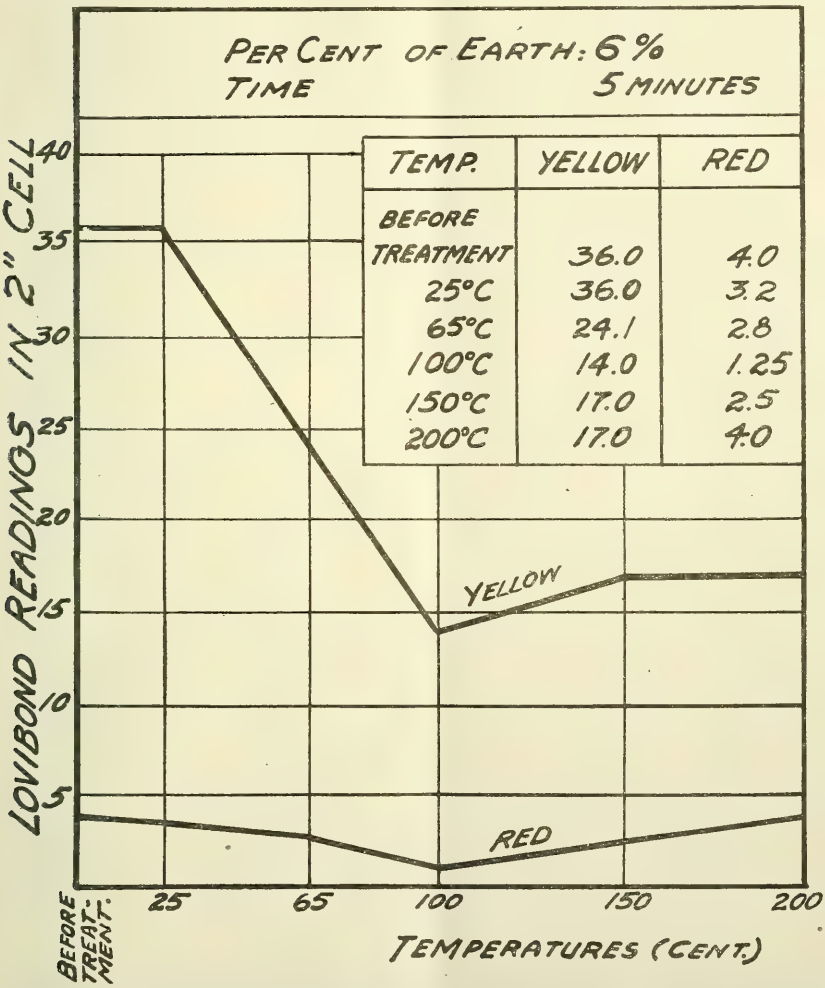

FIG. 2.—Relation between the temperature maintained and the extent of the bleaching affected.

at temperatures of 25°, 65°, 100°, 150°, and 200° C., respectively. In each case the oil was uniformly stirred and heated to the desired temperature, whereupon the earth was added slowly and the stirring continued for five minutes. The mixture was then filtered through a force filter. Figure 2 illustrates the results obtained.

It is evident that the proper temperature at which to effect the treatment is about 100° C. At 25° C. practically no bleaching is

obtained, while at temperatures considerably above 100° C. a less pronounced bleaching is effected. Since the oil must be dehydrated at a temperature somewhat above 100° C., treatment with fuller's earth at temperatures below that point, even if effective, would not be practicable, since time would be lost in waiting for the oil to cool.

In this connection, some tests were made to determine the bleaching effect of heating without the fuller's earth. Two 300-gram samples of oil, (*a*) of average color, and (*b*) of materially darker

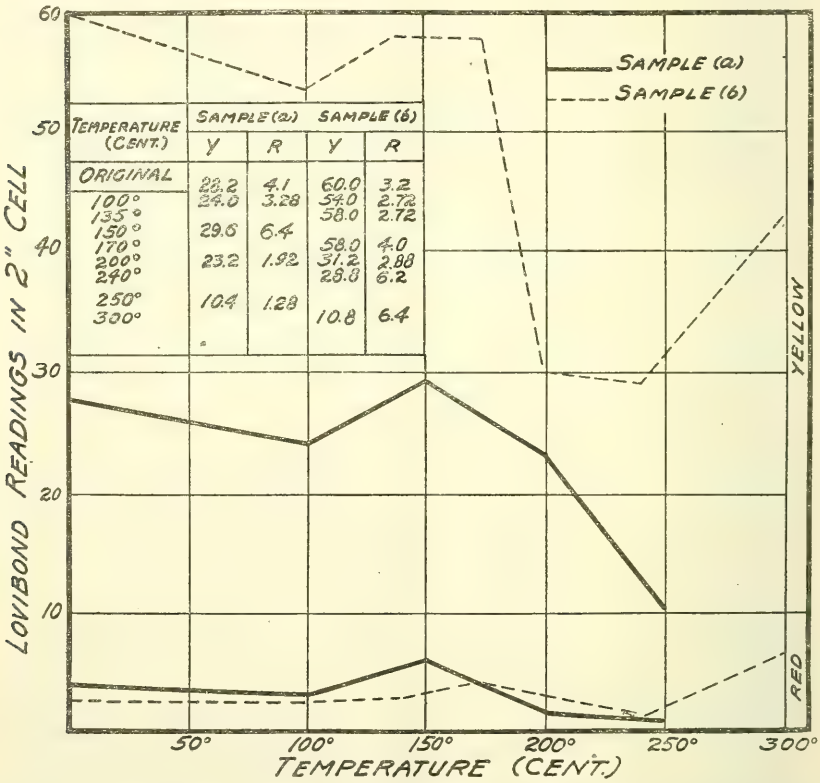

FIG. 3.—The extent of bleaching effected in two samples of corn oil when heated to various temperatures up to 300° C.

color, previously treated with caustic, were heated slowly, with constant stirring, to 250° C. At 100°, 150° and 200° C., respectively, the temperatures were maintained constant for five minutes; then samples for colorimetric readings were withdrawn and the heating continued. Figure 3 shows the extent to which the heating bleached these oils. A decided bleach seems to be effected at a temperature of 200° to 250° C. Above that temperature the oil apparently turns darker. Both samples of oil bleached slightly up to 100° C., then darkened somewhat until 150° C. was reached, and then bleached again as the temperature rose to 250° C. It is generally recognized

that some vegetable oils will lighten in color on heating, but individual oils differ in this respect. Corn oil does not appear to bleach to a sufficient extent under this treatment alone.

The third experiment was designed to show the influence of the period of contact of the earth with the oil on the bleaching effected

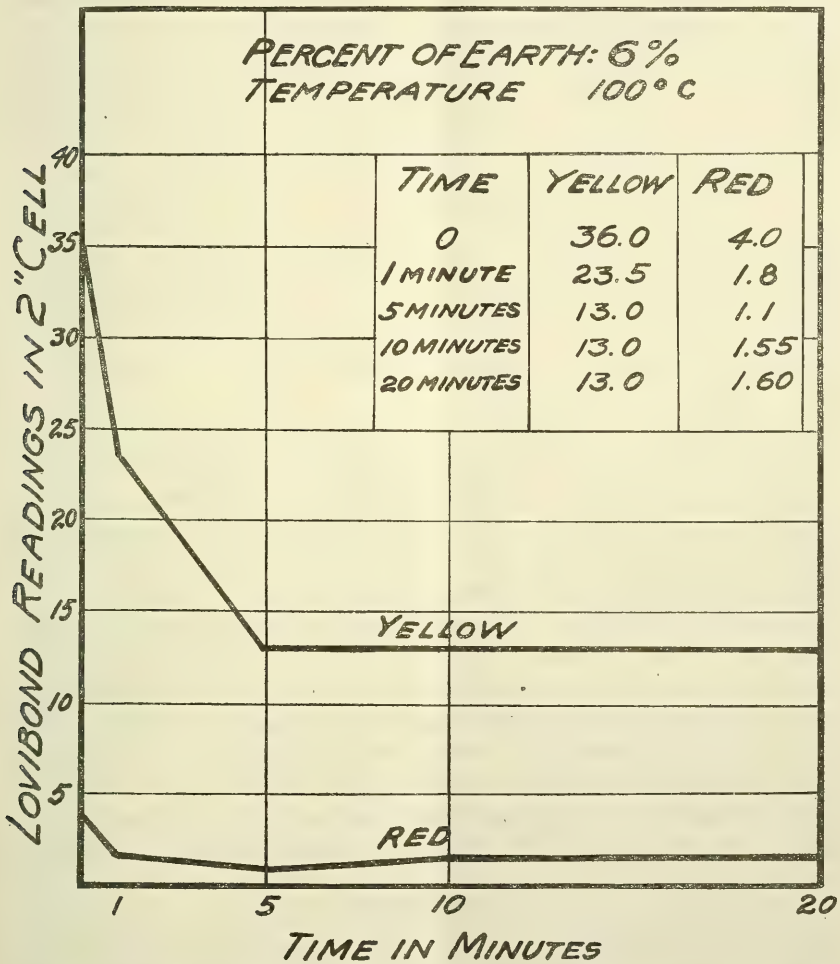

FIG. 4.—Relation between the time of contact with the fuller's earth and the bleaching effected.

Six per cent of standard fuller's earth was used at a temperature of 100° C. for periods of 1, 5, 10, and 20 minutes, respectively. From figure 4 it is evident that the maximum bleaching effect is obtained after a 5-minute contact and that about half of the bleaching is accomplished in the first minute.

Some difference of opinion exists as to whether fuller's earth effects a more efficient bleach if previously dehydrated. It is said to be the

practice among some refiners to roast the earth, while others claim that the temperature used should be only high enough to remove external moisture and that excessive heating affects the porous character of the earth. Accordingly, three samples of oil were bleached with earth treated as follows: (1) No dehydration, (2) heated at 100° C. for 15 hours, and (3) roasted at high temperature for five minutes. Table 4 shows the results.

TABLE 4.—*Effect of the degrees of dehydration on the bleaching efficiency of standard fuller's earth.*

Treatment of the earth.	Color.[a]	
	Yellow.	Red.
No dehydration	[b] 13.0	1.1
Dehydrated at 100° C. for 15 hours [c]	21.5	1.1
Roasted at high temperature for five minutes	16.5	.9

[a] Colors read in 2-inch cell.
[b] Color of the oil before treating with earth: Yellow, 36.0; red, 4.0.
[c] This treatment resulted in a 12 per cent loss in moisture.

This experiment was repeated with almost identical results. Earth previously roasted effected a slightly better bleach on the red but somewhat poorer on the yellow, while earth dehydrated at 100° C. appears to be the least beneficial, for reasons not yet apparent. It appears, therefore, that better results are obtained on corn oil by using fuller's earth as it is found on the market.

Some oils can be more effectively bleached by means of a decolorizing carbon or a combination of such carbon with fuller's earth. Four of the principal commercial decolorizing carbons were tested on corn oil, alone and in combination with fuller's earth. The color of the oils thus treated was so manifestly the same that no readings were made, but the conclusion is warranted that the color in corn oil is not removed to any practicable degree by these carbons.

A further bleaching is effected during the deodorizing process.

DEODORIZING.

The process of deodorizing is the third and last principal step in the preparation of an edible oil. The trade demands an oil which is as nearly as possible without deleterious odor and taste, and it is mainly to remove such odor and taste that this last process is necessary. The treatment as followed at the present time has a further value, however, in that it frequently effects a considerable bleaching at the same time.

The method employed in the deodorization of oils consists essentially in blowing steam through the heated oil, usually under reduced pressure. This removes all volatile constituents and leaves a bland

oil with practically no unpleasant odor or taste. The details of the process differ somewhat, according to the kind of oil that is being treated. In the case of corn oil the object of the deodorizing process is to remove the peculiar cereal flavor which is so characteristic of the oil.

The experiments performed in the deodorization of corn oil were conducted with a view of determining the proper temperature to be maintained and the time of treatment necessary to give the oil the best flavor and at the same time the lightest color. Some preliminary experiments consisted in blowing the previously neutralized and bleached oil with steam under atmospheric pressure. After four or five hours of such treatment the oil when separated from the condensed steam was found to be entirely odorless, but the color was not improved to any great extent. The oil thus treated was then divided into three lots, two of which were dehydrated and the other kept as a check. Table 5 gives the condition of the three oils after standing in well-filled bottles for some time.

TABLE 5.—*Effect of the presence of moisture on the keeping quality of deodorized corn oil.*

Sample.	Treatment for removing moisture.	Quality of oil after—		
		One week.	Four weeks.	Twelve weeks.
No. 1	None	Slightly rancid	Distinctly rancid and somewhat musty odor.	Very rancid and musty.
No. 2	Heated under vacuum to 95° C. for one hour.	Good quality	Good quality	Rancidity becoming noticeable.
No. 3	Stream of carbon dioxid passed through the oil for seven hours at 70° C.	do	do	Good quality.

It is evident that although steam at ordinary pressure volatilizes the odorous constituents of the corn oil and produces a very acceptable product as regards taste and odor, the oil must subsequently be dehydrated in order to prevent it from rapidly becoming rancid.

With very few exceptions vegetable oils are deodorized in commercial practice by blowing steam through the oil at a temperature of about 200° to 250° C. (392° to 437° F.) under high vacuum for about an hour, the time depending to some extent upon the character of the oil and the type of equipment. The object is to obtain an oil of satisfactory color and taste in the shortest time possible.

The oil is heated to 200° C. in the deodorizing tank either by direct heat or by means of superheated steam in closed coils placed in the bottom of the tank. Steam is then blown through the oil from a perforated coil. The practice differs with respect to this process, in some cases the steam being superheated. It is evident, however, that the use of superheated steam for this purpose will aid in keeping

the oil at the desired temperature. After the oil is steamed for the necessary length of time the steam is turned off and the oil cooled under the reduced pressure to ordinary temperature.

In the experimental work on this process conducted in the laboratory, the oil was heated in a round-bottom glass flask on a sand bath by means of gas burners to 105° C. under a vacuum of 25 inches; the steam was then admitted and the heating continued to the desired temperature. All the experiments were conducted in a darkened room in order to avoid any possible bleaching effect of the light.

Two principal determinations were sought in this experimental work: (1) The proper temperature to be maintained and (2) the length of time necessary to give the best product. In determining the results obtained two qualities were considered: (1) The extent of the deodorization as indicated by the taste, odor, and acidity and (2) the bleaching effect obtained. In the first experiment samples of corn oil, previously neutralized and bleached with fuller's earth, were deodorized at 150°, 200°, and 300° C., respectively, the time of treatment varying from 15 to 120 minutes. The samples treated at 200° C. (392° F.) were uniformly of a very acceptable quality, even the one treated for only 15 minutes being entirely devoid of the peculiar cereal odor and taste of the untreated oil. The samples deodorized at 150° C. (302° F.) were practically the same in this respect. Those treated at 300° C. (572° F.) appeared to possess a slightly charred odor.

Table 6 shows the effect of the treatment on the percentage of free fatty acids.

TABLE 6.—*Percentage of free fatty acids in corn oil deodorized under various conditions.*

Temperature.	Percentage of free fatty acids [a] after treating for the number of minutes specified.						
	15	30	45	60	75	90	120
150° C	0.055	.....	0.03	.....	.....	0.027	.....
200° C	.07	0.046	.05	0.047	0.032	.023	0.024
300° C	.057	.....	.045	.....	.....	.025	.....

[a] The sample of corn oil used contained before the treatment 0.061 per cent of free fatty acids.

Before being deodorized by the foregoing method the oils gave a positive reaction for aldehydes by the Kreis test,[7] but after the deodorization the reaction was negative in all cases.

The treatment as described had a very marked bleaching effect. Figure 5 illustrates the extent to which bleaching was effected at the several temperatures.

[7] Kerr, Robert H. Chemical tests for the detection of rancidity. *In* Jour. Indus. Engin. Chem., v. 10, no. 6, p. 471-475. 1918.

It is quite evident that the maximum bleach is obtained within the first hour of treatment. This is uniformly true at the three temperatures used in this experiment. At 150° C. the oil darkened during the first 15 minutes, increasing both in yellow and red, and then started to bleach, reaching its maximum in 45 minutes. At the higher temperatures the bleaching began at once and continued rapidly during the first 15 minutes, reaching its maximum in 60 minutes in the sample maintained at 200° C. and in 45 minutes in that at 300° C. The data included in figure 5 show that the bleach-

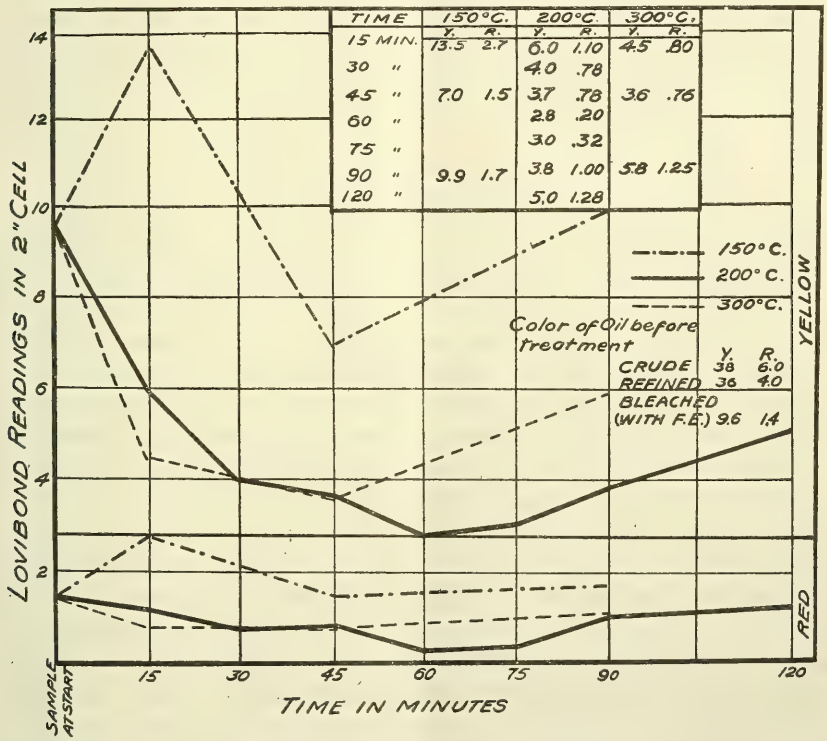

FIG. 5.—The extent of the bleaching effected by the deodorizing treatment continued for various periods and at various temperatures.

ing effect obtained at 200° C. was greatest, resulting in a very light oil. The foregoing experiments justify the conclusion that corn oil can be effectively deodorized and bleached by treatment with saturated steam at 200° C. under a vacuum of 25 inches for one hour.

Since the bleaching obtained was so apparent, two samples of oil from the same source but not previously bleached with fuller's earth were deodorized at 200° C. for two and four hours, respectively. Table 7 shows the extent to which the oil was bleached and also a comparison of the results with those obtained from treating the oil with fuller's earth.

TABLE 7.—*Comparative bleaching effect of fuller's-earth treatment and the deodorizing process (200° C.) on corn oil, as indicated by Lovibond color readings in a 2-inch cell.*

Nature and time of treatment.	Color.	
	Yellow.	Red.
No treatment	60.0	4.8
Deodorization for two hours	10.4	3.2
Deodorization for four hours	11.2	3.6
Treatment with fuller's earth	19.2	4.0
Treatment with fuller's earth and subsequent deodorization for two hours at 200° C.	5.0	1.3

From these experiments it is evident that the deodorizing process results in a greater bleaching of the oil than the treatment with fuller's earth alone, but the finished oil is by no means as thoroughly bleached as when both treatments are employed.

COMPARATIVE REFINING QUALITIES OF CORN OIL FROM DRY AND WET PROCESS GERMS.

The manufacture of corn products falls into two general classes. In the manufacture of meal, flour, and hominy products it is necessary that the corn be degerminated in the dry condition; in the manufacture of the various starches and glucose products the corn is first thoroughly soaked before being degerminated.[8] This difference in the degerminating methods gives rise to two types of oil. The oil produced from the wet-process germs has a tendency to contain a somewhat higher percentage of free fatty acids. In other respects the two types are fairly similar.

To determine the relative quality of the edible oil obtainable from each of these two types of oil a sample of each was neutralized, bleached, and deodorized by the methods described. Sample A consisted of a composite mixture of oils from five large hominy mills, and sample B was a composite of oils from five starch and glucose plants. Of these crude samples oil A contained 0.92 per cent of free acids and oil B contained 2.17 per cent. Oil B was slightly darker than oil A. Both oils gave positive reactions to the Kreis reagent for aldehydes in dilutions of 1 to 20.

The oils were treated with caustic soda according to method 2, thus reducing the percentage content of acids to 0.019 in oil A and 0.023 per cent in oil B. A slight bleaching resulted from this treatment. The Kreis reagent showed a weak reaction for aldehydes in both oils at dilutions of 1 to 10. Both oils were then bleached with 6 per cent of fuller's earth, according to the method described. The treatment reduced the color in A to 10 yellow and 1.0 red and in B to 19.2 yellow and 3.0 red (2-inch cell).

[8] Sievers, A. F. The production and utilization of corn oil in the United States. U. S. Dept. Agr. Bul. 904, 23 p. 11 figs. 1920.

The deodorization of these oils was extended over a long period, in order to determine just what effect such a protracted treatment would have. The oils were allowed to cool at 2-hour intervals, so that small samples might be removed to determine the color and free acidity. The process was then continued for another period, and so on. Table 8 shows the effect of the process of deodorization on the formation of free acids.

TABLE 8.—*Percentage of free fatty acids in corn oil from dry and wet process germs after various treatments.*

Sample.	Crude.	Alkali treated.	Deodorized—			
			Two hours.	Four hours.	Six hours.	Eight hours.
Oil A.....per cent..	0.92	0.019	0.024	0.02	0.042	0.047
Oil B.....do....	2.17	.022	.032	.04	.051	.056

The diluted oils showed at all four stages of the deodorization treatment very slight reactions for aldehydes with the Kreis reagent.

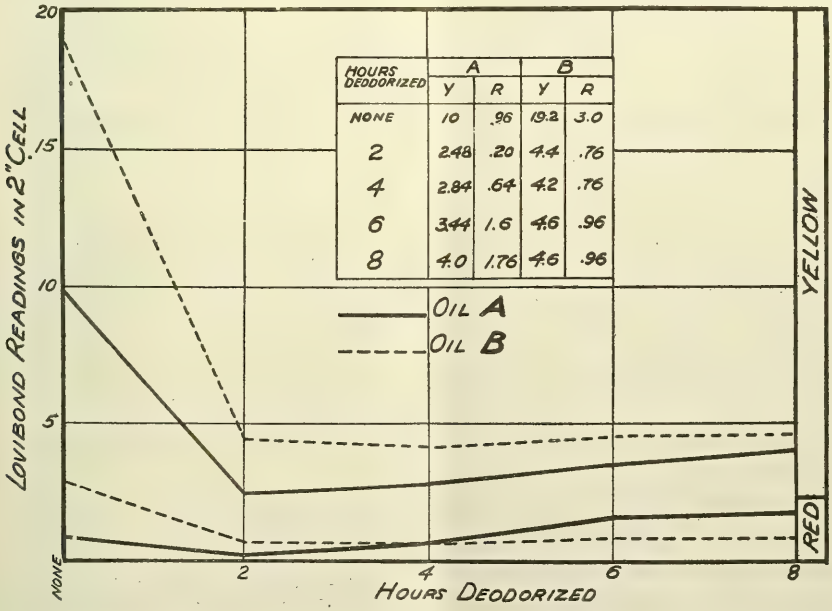

FIG. 6.—The comparative bleaching of oils A and B by the deodorizing treatment during successive 2-hour periods.

The marked effect of the deodorization treatment on the color of the oils is shown graphically in figure 6. The results obtained are further evidence that the bleaching is effected in the early stage of the process. Though oil B was considerably darker than oil A before they were deodorized, the finished oils after eight hours of treatment

were very nearly the same color, B having less red but slightly more yellow than A. In fact, after two hours of treatment a comparison of the two oils leads to the conclusion that the color of the finished oil is not materially dependent upon the germs from which it is produced, whether from the dry or the wet process.

REFINING 10-POUND BATCHES OF CORN OIL TO DETERMINE THE COST OF THE CHEMICALS USED AND THE VALUE OF THE OIL LOST.

On the basis of conclusions drawn from the foregoing experiments on small quantities of oil, two batches of 10 pounds each were refined. The oil was obtained from a hominy plant and was therefore produced from dry-process germs. It contained 1.76 per cent of free fatty acids. One of the 10-pound batches was treated with caustic according to method 1, and the other batch according to method 2.

TREATMENT WITH CAUSTIC.

The 10-pound batch of oil to be treated by method 1 was placed in a 12-quart enameled bucket. A pound of 10° Bé. caustic was added and the mixture stirred for 30 minutes. Heat was then applied slowly with continued stirring over a period of 15 minutes until a temperature of 55° C. was reached. The break occurred as the temperature reached 45° C. The oil was warmed for three hours in a water bath at 55° C. and then allowed to cool to room temperature by standing overnight.

The oil, which will be designated C, was removed from the soapstock by suction through a rubber tube which could be moved about over the surface of the soapstock, a method similar to the commercial practice of pumping off the oil and skimming off the last portion by means of a swivel pipe. The soapstock was of a soft-petrolatum consistency, and the oil could all be drawn off with the exception of a thin layer. The refining loss was 6.05 per cent. Heating the soapstock did not result in separating out any more of the oil.

The neutralized oil was turbid, owing to the presence of moisture and soap. To remove the soap the oil was heated to 65° C. in the bucket, with constant stirring, and 5 per cent of a 10 per cent brine solution was added in a fine stream. Stirring was continued for 15 minutes and the oil then allowed to stand. The bulk of the brine settled out rapidly, but a turbidity remained in the oil even after it had stood all night. This turbidity was due to moisture rather than to soap, since heating completely clarified the oil and left no particles of soap in suspension, as was the case before the oil was washed.

The other 10-pound batch of oil was treated with 14° Bé. caustic according to method 2. The quantity required to neutralize the

free fatty acids, plus 50 per cent excess, was added gradually and the mixture stirred for 30 minutes. After the temperature had risen gradually over a period of 15 minutes to 55° C. and the break had taken place, 2 per cent of soda ash was added and the stirring continued for five minutes. After warming for three hours and cooling overnight, the oil, which will be designated D, was drawn off in the manner described for oil C. The refining loss was 7.35 per cent. The soapstock was firm but contained considerable oil. After several holes had been cut in this soapstock with channels draining toward them, the bucket was placed on a steam bath for about 15 minutes. The holes quickly filled up with the oil, which was then drawn off. Several times these holes filled up, and by this means sufficient oil was recovered to reduce the refining loss to 5.44 per cent.

The neutralized oil, although somewhat turbid, contained no soap and consequently did not require washing. In this respect method 2 appears to have a distinct advantage over method 1.

BLEACHING.

Both oils were treated exactly alike from this point on. They were first dehydrated at 110° C., with constant stirring for 10 minutes. Five per cent of standard fuller's earth was then added and the stirring continued for 15 minutes with the temperature at about 105° C. The oils were then filtered rapidly through a Buchner funnel.

DEODORIZING.

Since there was at hand no apparatus large enough to deodorize the large quantities of oils C and D, smaller quantities of each were used. In each case the oil was treated at both 200° and 225° C. (392° and 437° F.) in glass flasks for one hour under a vacuum of 25 inches. A comparison of the finished oils is given in Table 9.

TABLE 9.—*Comparison of oils C and D after finished treatment.*

Oils and methods.	Color (5¼-inch cell).								Free fatty acids after deodorizing at 200° C.	General quality of finished oils.
	After treatment with caustic.		After bleaching.		After deodorizing at—					
					200° C.		225° C.			
	Yellow.	Red.	Yellow.	Red.	Yellow.	Red.	Yellow.	Red.		
									Per cent.	
Oil C, method 1.	35	5.2	35	2.8	20	1.8	13	1.5	0.092	Odorless; no cereal taste; comparable to best commercial sample.
Oil D, method 2.	35	5.6	35	3.3	16	2.0	16	2.0	0.083	

ESTIMATED TOTAL COST OF REFINING CORN OIL.

The cost of refining vegetable oils includes such items as cost of chemicals, value of the oil lost in the several processes, fuel, labor, and overhead. In a relatively small refining operation, such as is here described, it is quite impossible to allocate the fuel, labor, and overhead expenses to the several operations. Accordingly, these items are charged in an estimated over-all cost of producing the finished edible oil. The cost of the chemicals used and the value of the oil lost are, however, highly specific to the several operations and can be charged thereto with a fair degree of accuracy.

TABLE 10.—*Cost of chemicals used and value of oil lost in treating 25,000 pounds of corn oil, containing 1.76 per cent of free fatty acids, by methods 1 and 2.*

Items of comparison.	Method 1.	Method 2.
Weight of oil ..... pounds	25,000	25,000
Weight of free fatty acids (1.76 per cent) ..... do	440	440
Sodium hydroxid necessary to neutralize the free fatty acids ..... do	62.8	62.8
Total sodium hydroxid necessary ..... do	[a] 163.7	94.2
Soda ash required ..... do	.....	500
Cost of caustic [b]	$8.19	$4.71
Cost of soda ash [c]	.....	10.00
Value of oil lost in treatment, at 10 cents a pound:		
Method 1 (6.05 per cent)	151.25	.....
Method 2 (5.44 per cent)	.....	136.00
Total cost (chemicals and value of oil lost)	159.44	150.71
Net cost (total cost, less the value of the soapstock, [d] $15.20 by method 1 and $17.32 by method 2)	144.24	133.39
Net cost of chemicals used and value of oil lost per pound of crude oil ..... cent	0.577	0.533
Net cost of chemicals used and value of oil lost per pound of refined oil ..... do	0.628	0.564

[a] Method 1 requires 10 per cent of 25,000 pounds, or 2,500 pounds, of 10° Bé. caustic (6.55 per cent NaOH), equivalent to 163.7 pounds of sodium hydroxid.

[b] Caustic soda containing 76 per cent of sodium hydroxid is quoted at $3.75 per hundredweight, which is equivalent to 5 cents a pound of 100 per cent sodium hydroxid, delivered.

[c] Soda ash is quoted at $2 per hundredweight.

[d] Soapstock is valued according to its fatty acid content. The value of soapstock for methods 1 and 2 is derived as follows: Weight of soapstock—(1) Caustic (sodium hydroxid solution), method 1, 2,500 pounds; method 2, 1,000 pounds. (2) Soda ash, method 2, 500 pounds. (3) Oil lost, method 1, 1,512.5 pounds; method 2, 1,360 pounds. Total, method 1, 4,012.5 pounds; method 2, 2,860 pounds. The weight of fatty acids in the soapstock is calculated as follows: (1) Total weight of oil lost (oil and free acid), method 1, 1,512.5 pounds; method 2, 1,360 pounds. (2) Weight of free acids, method 1, 440 pounds; method 2, 440 pounds. (3) Weight of oil lost, method 1, 1,072.5 pounds; method 2, 920 pounds. (4) Weight of fatty acids in oil lost, method 1, 986.3 pounds; method 2, 846 pounds. (5) Total weight of fatty acids, (2)+(4), method 1, 1,426.3 pounds; method 2, 1,286 pounds. (6) Total weight of soapstock, method 1, 4,012.5 pounds; method 2, 2,860 pounds. (7) Fatty acids in soapstock, method 1, 35.5 per cent; method 2, 44.9 per cent. The money value of the soapstock is calculated by the following formula: $R \times P \times M \div 50 =$ value (dollars). In this formula R is the weight of the fatty acids (in pounds), P is the percentage of fatty acids in the soapstock, and M is the market price per pound (in dollars). If soapstock containing 50 per cent of fatty acids is quoted at $0.015 per pound, the value of the soapstock, according to this formula by method 1 is $1,426.3 \times 35.5 \times .015 \div 50 = \$15.20$. By method 2 the value is $1,286 \times 44.9 \times .015 \div 50 = \$17.32$.

CHEMICALS AND LOSS OF OIL.

It is evident that a very good quality of oil can be produced by both methods 1 and 2; hence, from this standpoint either method is practicable. The choice of the methods would appear, therefore, to depend upon which would be the more economical when such factors as loss of oil, cost of the chemicals used, and the time involved are considered. The cost of these items has been estimated on the basis of the results of refining the 10-pound batches for treating 25,000

pounds [9] of corn oil containing 1.76 per cent of free fatty acids, and a comparison of these estimates for both methods is presented in Table 10.

TREATMENT WITH CAUSTIC.

The difference in cost of chemicals and value of oil lost in the two methods is 0.064 cent per pound of refined oil in favor of method 2. This slightly lower cost of method 2 is due to the lower refining loss of oil and the slightly greater value of the soapstock, although the cost of the chemicals is higher than in method 1.

Since both methods were found to give a good quality of oil and since the difference in cost is not considerable, there would appear to be little, if any, advantage of one method over the other. As has been previously stated, however, method 2 does not require the washing of the oil with brine to remove the traces of soap, and this is a distinct advantage, especially from the standpoint of the time involved. On the other hand, this method calls for special handling of the soapstock in order to reduce the refining loss to the figure given in Table 10. In this respect method 1 has the advantage. It would appear, therefore, that the two methods are practically of equal value as to the ease of operation and cost.

BLEACHING.

In commercial practice it is generally assumed that the bleaching of vegetable oils with fuller's earth results in a loss of oil equivalent to 20 per cent of the weight of earth used. On this basis, the cost of the bleaching operation on the quantity of oil under discussion as regards the cost of earth and the value of the oil lost would be as shown in Table 11.

TABLE 11.—*Cost of material used and value of the oil lost in bleaching corn oil with fuller's earth.*

Items of comparison.		Method 1.	Method 2.
Weight of oil to be bleached	pounds	23,487	23,640
Quantity of fuller's earth required (5 per cent) [a]	do	1,174.3	1,182
Loss of oil by treatment (20 per cent of weight of fuller's earth)	do	234.8	236.4
Cost of fuller's earth (2¼ cents a pound)		$26.42	$26.59
Cost of oil lost (10.5 cents a pound) [b]		24.65	24.82
Total		51.07	51.41
Cost of above items per pound of crude oil	cent	0.204	0.206
Cost of above items per pound of bleached oil	do	.22	.22

[a] This is a greater percentage of fuller's earth than is used for most vegetable oils, but commercial practice and laboratory tests appear to agree that such a quantity is necessary in the case of corn oil.
[b] This figure represents the cost of crude oil plus the approximate cost of the treatment with caustic.

[9] The refining equipment described in this bulletin is designed to handle 50,000 pounds of oil a week. This quantity of oil would be produced in a hominy plant milling from 15,000 to 18,000 bushels of corn daily. In a starch plant, which produces at least twice as much oil from the same quantity of corn, the refinery would need to be proportionately larger.

The cost of the material used and the oil lost in the bleaching operation after treating the oil with caustic amounts to about 0.21 cent a pound of crude oil, of which approximately one half represents the cost of the fuller's earth and the other half the value of the oil lost in the operation.

DEODORIZING.

Deodorizing is an entirely mechanical operation and involves no charge for chemicals. There is a small loss of oil in the entrainment, which varies according to the local conditions, but even this small quantity of oil is recovered by means of the grease trap in the sewer.

FUEL.

The cost of fuel for caustic treatment and bleaching is comparatively low. For deodorization, however, the fuel charge is the main item of cost. Not only must the oil itself be heated to over 400° F., but it must be maintained at this temperature while approximately 25,000 pounds of steam are blown through it. Unless the steam has been previously superheated, it is evident that its passage through the oil will raise its temperature to that of the oil itself, which would operate to lower the temperature of the oil. Therefore not only must 25,000 pounds of steam be generated but it must be superheated to at least 450° F. before it can effectively serve its purpose. The oil itself must likewise be raised to this temperature, all of which accounts for the large quantity of fuel used. This consists not only of coal as burned under plant boilers for steam but also of fuel oil used in the direct-fired oil heater.

LABOR.

The labor necessary for handling the oil through the refinery is quite evenly distributed among the three principal operations. It is estimated that two men—one skilled workman and one unskilled laborer—can operate the plant under the general direction of the chemist and plant superintendent. A charge of $13.80 is made for these two workmen for each of the three operations, or a total of $41.40 for each batch of 25,000 pounds of oil. The cost of the technical supervision is charged to overhead by including the salaries of the chemist and plant superintendent with those of the general executive force and assuming that a tenth of their time will be devoted to matters connected with the refinery.

OVERHEAD.

The overhead item covers all plant charges not enumerated in the above, and consists of such costs as the following: Interest on a $40,000 equipment, building charge, water, insurance, power, office expenses, and selling charges.

Table 12 shows the distribution of costs for the several processes involved.

TABLE 12.—*Distribution of costs of refining 25,000 pounds of corn oil.*

Items.	Neutralizing.	Bleaching.	Deodorizing.	Total.
Chemicals	[a] $14.71	$26.59	.....	$41.30
Loss of oil	[b] 118.68	24.82	.....	143.50
Fuel	.50	.75	$12.42	13.67
Labor	13.80	13.80	13.80	41.40
Overhead	.....	.....	.....	161.19
Total	.....	.....	.....	[c] 401.06

[a] Caustic treatment according to method 2.
[b] This figure is obtained by subtracting the value of the soapstock from the value of the oil lost.
[c] Cost per pound, 1.6 cents.

DESCRIPTION OF THE EQUIPMENT AND THE METHOD OF HANDLING CORN OIL IN THE REFINERY.

The refinery illustrated in figure 7 is designed for installation in a corn-oil expelling plant. Since such a plant is generally provided with storage facilities for crude oil, the refining equipment as here designed provides for only one tank, *A*, for this purpose. When this tank is about full (the product of half a week's run) the oil is pumped into the refining tank *B*. It will be observed that the delivery pipe is tapped into the tank near the bottom. This arrangement is for the purpose of avoiding the churning and excessive foaming contingent upon introducing the oil over the top of the tank, as is usually done. The oil is here refined, as previously described, and then allowed to stand, usually overnight, to allow the soapstock to settle out. The supernatant clear oil is then drawn off by means of a swivel arm and pumped to tank *C*, while the soapstock in the cone-shaped bottom is softened by steam coils and allowed to flow into the soapstock tank *d*, for subsequent filling into barrels. In a large refinery this is not the cheapest disposition, but in a small one it is probably the most practicable.

The small tank *a*, provided with barrel rests, receives the caustic soda for refining. The lye is transported by the monte-jus *a′* (closed tank provided with air pressure) to the weak-lye tank *b*, where the volume (or weight, if the tank is on scales) is adjusted for the given batch of oil. Tank *c* is for miscellaneous chemicals used from time to time for special treatment of the oil, such as salt and soda ash.

If the oil is to be washed, it is heated to approximately 165° F. and washed by spraying with about 5 per cent of hot water, or, better, with a 10 per cent brine solution, after which the water is allowed to settle out. The coils not only bring the oil up to the required temperature but assist in the separation of the moisture suspended in the oil. The water is drawn off from the bottom of the tank and

flows into the general sewer, whereby any entrained oil may be recovered. If more than traces of moisture remain, the oil must be agitated and heated in order to dry it. The fuller's earth, previously weighed out in room *e* on the mezzanine floor over the tanks, is dropped into the oil in the tank *C*, which is covered during this operation to prevent the spreading of the dust. After agitating for about half an hour, the batch is pumped through the filter press *E* and allowed to run back into tank *C* by the sliding funnel until the cloths

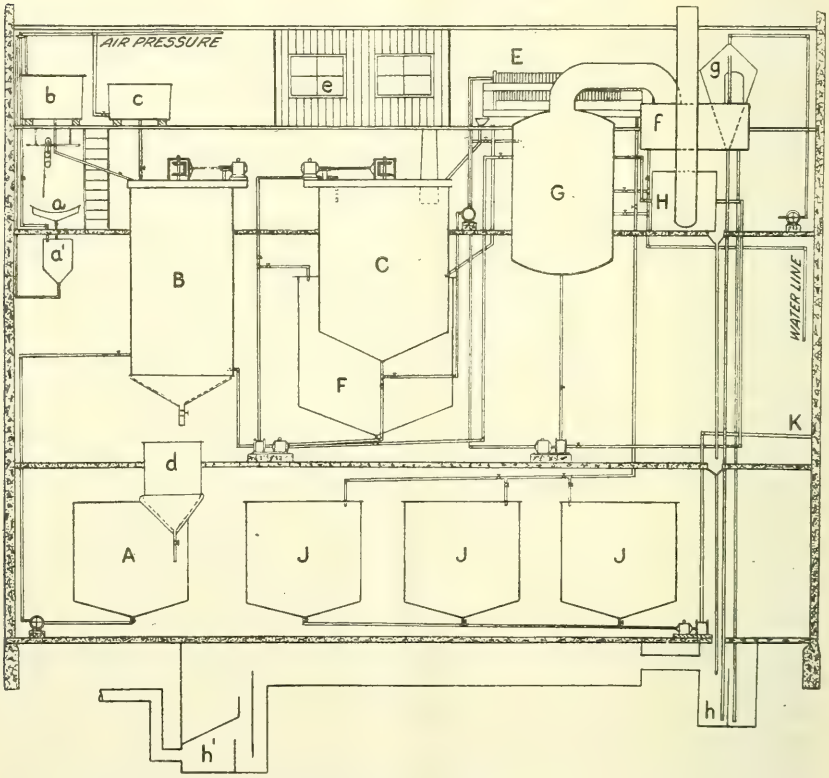

FIG. 7.—Plan of an equipment designed for refining 25,000 pounds of corn oil at one time.

of the press have been covered and the oil flows clear. It is then run into tank *F*, which serves as a storage tank for the deodorizer.

Up to this point each unit of the equipment has been large enough to handle a batch of about 25,000 pounds of oil. The deodorizer, however, is designed for only half of this quantity. In the first place the larger the batch of oil the longer it must be subjected to the deodorizing treatment. This treatment benefits an oil up to a certain point, but if it is continued beyond that point the oil deteriorates. The smaller installation also means a lower overhead in the nature of certain fixed charges. The distribution of labor among the several

operations in a refinery like the one under consideration is such that the two workmen have ample time to deodorize the oil in two batches.

The principle involved in deodorization is that of blowing live steam through the oil for several hours at temperatures above 400° F. under a very high vacuum. For the most effective results the steam must be brought into very intimate contact with the oil, which is accomplished by introducing the steam into the deodorizer through numerous minute perforations in a series of pipes emanating from a header.

In the industrial application of this principle several different procedures are followed. In some plants the oil is heated by closed steam coils to as high a temperature as is possible with the regular factory boiler steam and is then blown, either with some of the same steam or with a separate line of superheated steam. Others heat the oil with ordinary factory steam or with superheated steam in closed coils until nearly the required temperature is reached and then turn in the open steam, likewise superheated. The tendency seems to be to use open steam at as low a pressure as is practicable.

The great difficulty in heating the oil by superheated steam is that it is practically impossible to attain the desired temperature by such means. Since it is entirely feasible to carry superheated steam at a temperature of 600° F. it would appear to be a simple matter to use it to maintain oil at a temperature of 400° to 440° F. As a matter of fact, however, it is almost impossible to accomplish this. Consequently, the oil is often heated in a direct-fired furnace, designed very much like a direct-fired ordinary steam superheater, substituting, however, the oil stream for that of the steam. Any desired temperature can be attained by such an arrangement, the control is good, and the performance satisfactory.

It has been calculated that the consumption of coal in a direct-heat deodorizer is about one-fifth of that used in one heated by superheated steam, which, in a batch of the above size (25,000 pounds), amounts to more than one-third of a cent per pound of oil. Of course if other uses can be found for the heat of the steam after it leaves the coils of the deodorizer there must be a credit entered against the coal charged to deodorization. But in a small refinery the intermittent character of this additional use precludes any serious attempt at its utilization. Expedition and skill are required in handling such direct-fired equipment, and great care must be exercised or a batch of oil will be burned. The pumping capacity for forcing the oil through the heater must be ample in order to prevent scorching, and there must be protection against mishap, such as stoppage of flow, since this would result in ruining the entire batch.

In a large refinery it may be more practicable to locate the oil heater near the boiler room of the plant, so that one crew of firemen and the coal and ash handling equipment can take care of all the fires;

but in the case of a small refinery, such as is here considered (fig. 7), this may be impracticable. Accordingly, the heater *H* is located near the deodorizer *G* and is arranged to burn fuel oil. This not only obviates the cost of handling coal and ashes but affords ready control, a fairly constant temperature, and can be so regulated that it does not require the undivided attention of the operator. The two workmen of the refinery, previously referred to, should be able to handle this equipment. A very decided advantage in using oil instead of coal for fuel lies in the ease with which the fire can be extinguished in case the pumps stop. If coal costs $6 delivered and fuel oil $2.50 a barrel,[10] the cost for heating is about the same, but the oil has the advantage of better control, greater cleanliness, absence of charges for handling ashes, and the saving in fireman's wages.

The steam, with its charge of volatile odorous vapors, passes into the tank *f*, which functions both as a trap and as a preliminary condenser, and then passes into the jet condenser *g*, where a curtain of water entering near the top condenses the steam and discharges it into the hot well *h*. The condenser discharge pipe is longer than that required to produce a Torricellian vacuum and therefore insures a good working vacuum. However, certain noncondensible gases accumulate in the peak of the condenser *g*, operating to lower the vacuum. These gases are removed by the auxiliary dry-vacuum pump through the line entering the condenser at the top. The water for the condenser *g* is the same as that used in the preliminary condenser *f*.

After deodorization, the oil must be cooled to atmospheric temperature under a high vacuum; otherwise the deodorized oil will deteriorate by oxidation. In some plants the oil is cooled by running it through a series of jacketed pipes. In the plant here considered the cooling is effected by turning a stream of water into the closed steam coils in the deodorizer and circulating the oil by the regular deodorizing pump. Sometimes a fine precipitate is found in the oil, particles are taken up from the equipment, or other circumstances develop which make it necessary to filter the oil through a clean filter press before storing in tanks *J*. The oil is pumped from these tanks through pipe *K* into cars.

All floors drain into the hot well *h*, which overflows into *h'*. This serves as a trap for any oil which may be spilled and that which is carried over with the deodorization vapors.

It must be recognized that although this treatment will give a high-grade edible oil, it can not be expected that such oil can be used for salad purposes without further treatment. Most vegetable oils

[10] This price is about an average of fuel-oil prices for 1919. Prices for 1920 are not included because of the abnormal conditions which prevailed in the oil market during that year.

contain more or less solid glycerids, which settle out when the oil is chilled. In order, therefore, to be sure that an oil will remain clear over the rather wide range of temperatures obtaining in the economy of the ordinary household, the oil must be chilled below the lowest temperatures to which it is likely to be subjected and then filtered.

SUMMARY.

The process of preparing an edible oil from crude corn oil consists of three distinct operations: (1) Neutralization with caustic; (2) bleaching with fuller's earth; and (3) deodorizing with steam.

Two methods of refining average corn oil are found to be about equally satisfactory. The soapstock obtained in refining corn oil is soft and slimy, and special means are necessary to harden it. In one of the proposed methods a large excess quantity of caustic is used, while in the other the same result is obtained by adding soda ash after the break. A maximum temperature of 55° C. is recommended in the refining of corn oil.

The value of the chemicals used and the oil lost in the treatment is 0.628 cent per pound of neutralized oil with method 1 and 0.564 cent with method 2, of which more than 80 per cent is represented by the loss of oil.

The oil is bleached with fuller's earth according to the method generally used. Not less than 5 per cent of earth must be used. Corn oil does not bleach as much by this treatment as some of the other vegetable oils. The cost of the materials used and the oil lost in this bleaching process is about 0.22 cent per pound of bleached oil, of which approximately half represents the value of the oil lost.

The oil is deodorized by being blown with steam for several hours at temperatures above 400° F. under reduced pressure.

The general arrangement of a refinery equipped to handle two batches of 25,000 pounds of oil a week is described and the passage of the oil through the several processes is discussed.

The cost of refining corn oil in such a plant as here described is found to be approximately 1.6 cents a pound. This cost figure was obtained by determining as nearly as possible the several charges for chemicals, oil losses, fuel, labor, and overhead. The overhead includes interest on the equipment and depreciation on both equipment and building. The value of the equipment, exclusive of the building, is estimated at $40,000.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 1011

Contribution from the Bureau of Plant Industry
WM. A. TAYLOR Chief

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EFFECTS OF MUTILATING THE SEEDS ON THE GROWTH AND PRODUCTIVENESS OF CORN.

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PREVIOUS INVESTIGATIONS OF THE EFFECTS OF THE REMOVAL OF FOOD RESERVES FROM SEEDS.

The effects of the removal or suppression of portions of the food reserves of the seed upon germination and upon the subsequent growth and development of the plant have been investigated extensively. Following is a brief account of some of the experiments that are more or less analogous to those reported in this bulletin.

Sachs (*5*)[2] was perhaps the first to germinate embryos of maize detached from the endosperm. They developed dwarf plants that soon perished. These germinations were made during the course of investigations upon the processes of germination, and there seems to have been no attempt to extend the experiments beyond the early stages of growth.

Van Tieghem (*8*) reports that in an experiment in which he dissected the plumule, the radicle, and the cotyledons out of seeds of *Helianthus annuus*, he found that these fundamental organs not only were capable of independent growth but each was capable of regenerating the other two and developing perfect plants. In somewhat

[1] The writer acknowledges his indebtedness to J. M. Hammerly and H. S. Garrison, of the Office of Cereal Investigations, for aid in conducting these experiments.

[2] The serial numbers (italic) in parentheses refer to "Literature cited," at the end of this bulletin.

similar experiments with maize embryos from which the plumules had been dissected, he succeeded in obtaining an extensive development of adventitious roots, but without the appearance of chlorophyll in the scutellum and without any extension of that organ or the formation of adventitious buds. Plants more than a month old showed an excellent system of roots but were without stem or leaves. The isolated scutellum was incapable of independent growth.

Blociszewski (*2*), in experiments with maize, rye, oats, clover, peas, and lupines, found the isolated cotyledons were capable of independent growth but formed only roots. Only that portion of the cotyledon to which the embryonic plant had been attached formed roots. Plants from isolated embryos were weak in the early stages of growth, but developed normally as soon as favorable conditions prevailed and were scarcely distinguishable from plants from entire seeds.

Wollny (*9*) conducted both laboratory and field experiments with peas, vetches, and rye. The field experiments are of special interest because they were conducted under ordinary agricultural conditions and were carried through to the maturity of the plants. He found that the removal of one-third to two-thirds of the cotyledons or endosperm of the seeds decreased the growth and yield of the plants. The reduction in growth and in yield was in direct proportion to the amount of food reserves removed from the seeds.

Stingl (*6*), working with rye, wheat, oats, and barley, found that the isolated embryos did not develop into normal plants. Artificially nourished embryos generally did not develop so well as plants grown from normal seeds. In general, oat endosperms used as nutriment for rye, wheat, and barley embryos exercised an unfavorable influence, whereas in no instance was a like unfavorable influence observed when oat embryos were nourished with endosperms of rye, wheat, and barley.

Delassus (*3*), experimenting with beans, vetch, and lupines, from which he removed various proportions of the cotyledons, obtained results similar to those of Wollny. The height of plants, the number and dimensions of the leaves, the number of flowers per foot of vine, and the number and size of fruits were all reduced. The disease resistance was lessened.

Dubard and Urbain (*4*) concluded from their experiments with the castor bean, maize, beans, and carrot that the albumen is never indispensable to the development of the young plant. Nevertheless, the influence of the albumen is favorable and appears to be particularly useful during the first days of germination.

Urbain (*7*) describes in detail experiments with Ricinus, Nigella, and Papaver and states that other experiments with maize and oats gave analogous results. He summarizes the effects of suppressing

the food reserves of the seed as follows: (*a*) Dwarfing the plants; (*b*) causing very apparent morphological modifications in the leaves; (*c*) causing a precocious but sparse flowering, in some instances the only flowering, in others followed by a second flowering at the normal period; and (*d*) causing frequent sexual anomalies in the course of the first flowering.

Andronescu (*1*) conducted experiments with maize in the laboratory and in the field. In the laboratory he dissected out the embryos, detaching them from the scutella, and succeeded in germinating them upon various nutrient solutions. He found that "the stem produced was the expansion of the mesocotyl and the elongation of the plumule sheath. One principal and two secondary roots, very poorly developed, were produced. In no case was the plumule able to split its sheath."

In the field experiments the embryos were not detached from the scutella and the plants were grown to maturity. The stalks from the embryos were shorter, of smaller diameter, and of fewer internodes than the stalks from the entire seeds. In general, the ears of the stalks from embryos were borne at lower nodes than the ears of the stalks from entire seeds. The ears from both the control and the test plants were imperfectly developed because of unfavorable weather during the growing season. No comparison of yield is shown.

The experiments that have been reviewed have dealt principally with plants other than corn; they have been conducted largely in the laboratory or greenhouse and frequently have not extended to the maturity of the plants. In some of the experiments the seed has been sown in the greenhouse and the plants later transferred to the field. These experiments would not be entirely representative of field conditions. In those that have been conducted under field conditions, corn either has not been among the species worked with or where it has been included the data obtained are incomplete.

EXPERIMENTS ON THE EFFECTS OF MUTILATION OF THE SEED COATS AND ENDOSPERMS.

The experiments reported in this bulletin, with the exception of those on the effect of mutilation of the embryo, were entirely under field conditions. The purpose was to determine the effects upon growth and productiveness that may be expected in a general way to result from the use of seed which from various causes is deficient in food reserves. These experiments are of additional interest because of the data they furnish upon the influence of the physiological condition of the seed in predetermining the subsequent development of the plant.[3]

[3] This subject has been interestingly discussed and reviewed by Kidd and West, Physiological Predetermination, in Annals of Applied Biology, v. 5 and 6, 1918, 1919.

In 1917 the experiments were conducted at the United States Experiment Farm, San Antonio, Tex., the Giles Farm, Waco, Tex., and the Yarrow Plant-Introduction Field Station, Rockville, Md.; in 1918 at the Rockville station; in 1919 at the Rockville station and at the Arlington Experimental Farm, Rosslyn, Va., near Washington, D. C.

PREPARATION OF THE SEEDS.

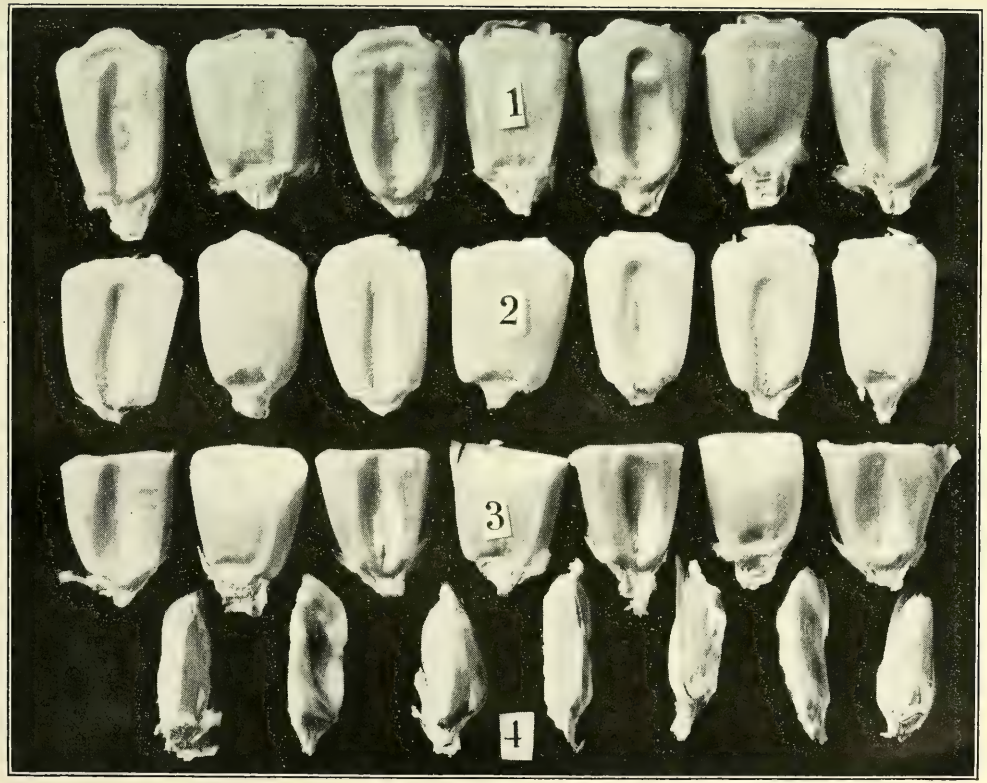
The preparation of the seeds used in the experiments conducted during the period from 1917 to 1919 was as follows: Four lots of seed were composited from four ears of United States Selection No. 119, a white dent variety, in such a manner that each ear was represented in the same proportions in each of the four lots. One lot received no injuries and was the "entire seed" or "check" (Pl. I, fig. 1), of the experiments. In the second lot (Pl. I, fig. 2), the seed coats, or hulls, were entirely removed. In the third lot (Pl. I, fig. 3), the crowns were cut off and as much of the soft starch removed as could be done without breaking the kernels. The hulls were not removed except the portion cut away with the crown. In the fourth lot (Pl. I, fig. 4), the entire endosperm was removed, leaving the isolated germ. The germ in the sense used in this article is the combined scutellum and embryo. The same methods of preparing the seed were followed each year. The different classes, for convenience in discussion, are termed check, dehulled, starchless, and germs.

PLAN OF THE EXPERIMENTS.

The plan of planting was the same each year and at all places. The following list shows the arrangement of the rows and the kind of seed planted in each row:

Row No. 1. Guard, United States Selection No. 119.
2. Entire seed.
3. Hulls removed, dehulled.
4. Hulls removed, dehulled.
5. Entire seed, check.
6. Soft starch removed, starchless.
7. Soft starch removed, starchless.
8. Entire seed, check.
9. Endosperm removed, germs.
10. Endosperm removed, germs.
11. Entire seed, check.
12. Guard, United States Selection No. 119.

The distance between rows and between hills in the row was 3.3 feet except at San Antonio, where the distance was 4 feet and 3.5 feet, respectively. The number of hills in each row varied from 22 to 25. The rate of seeding was four kernels to the hill, and the stands were thinned to two plants. No fertilizers were used.



KERNELS OF CORN SHOWING THE CHARACTER OF THE MUTILATIONS OF SEED COAT AND ENDOSPERM.

Fig. 1, entire kernels; fig. 2, kernels with hulls removed; fig. 3, kernels with soft starchy portion removed; fig. 4, endosperm removed, leaving isolated germ.

EXPERIMENTAL PLAT OF CORN GROWN FROM MUTILATED SEEDS IN 1917 AT THE YARROW PLANT-INTRODUCTION FIELD STATION, ROCKVILLE, MD.

The two rows of plants shown in the middle of the illustration are from the chipped seeds; the immediately adjacent row on either side is from entire seeds.

In harvesting, the stalks and suckers in each row were counted and the numbers recorded. The approximate average height of plants in each row was recorded. Each row was harvested separately and the ears weighed, counted, and classified into good and poor. If there appeared to be significant differences in moisture content the total product of each row was dried and the compared yields were based upon the dry weights. The plats were harvested from 140 to 155 days after planting.

EXPERIMENTAL DATA ON THE EFFECTS OF THE MUTILATION OF THE SEED COATS AND ENDOSPERMS.

The data presented in tabular form are dates of planting, emergence, and harvesting; ratio of actual stand to the possible stand three weeks after seeding; number of days from emergence to the first pollen shedding; number of plants per row when harvested; total and average weight of ears; total number of ears; average number of ears; and yield and corrected yield for each plant.

The corrected yield of a row was calculated by the formula $X = AB \div Y$, in which A is the actual yield of the row, B the average yield of all the check rows, Y the computed check yield for the row, and X the corrected yield of the row. In computing check yields for each row, the difference between the yields of two adjacent checks is divided by the number of intervening rows plus one and this quantity added to or subtracted from the yield of the successive checks as computed.

SAN ANTONIO EXPERIMENT.

The data from the San Antonio experiment are incomplete because of the effect of a long drought. Plantings were made on May 17. This late planting was necessary because the soil moisture previous to that date was not sufficient to insure the germination of the seed. The germination was rapid and uniform. Perfect stands were recorded on May 24 from the check seed and the starchless seed, but in the rows from dehulled seed and from germs there were a number of missing hills.

No differences were observed in the size and vigor of the seedlings from the check and the starchless seed. Those from the dehulled seed were smaller and less vigorous than the checks. Those from the germs were the smallest and least vigorous; they remained smaller than the other lots for several weeks, but at harvest were not noticeably smaller. The plants from the dehulled seed at maturity averaged slightly taller than the check.

The date of pollen shedding was the same for the four lots, beginning 52 days after the plants had emerged. There apparently were no differences in the time of ripening, probably differences that may

have existed in this respect being concealed by the effects of the drought. Although the plants made a fair growth, attaining a height of 6 to 10 feet, they failed to produce ears, and no data upon yields could be obtained.

WACO EXPERIMENTS.

The results obtained at Waco, Tex., presented in Table I, show that the stands three weeks after planting varied from 56 per cent of a perfect stand for the dehulled class to 98 per cent of a perfect stand for the check. Plants grown from the dehulled seed and from the germs averaged two days later than the check in date of first pollen shedding. Differences in time of ripening were not apparent. Drought sufficiently severe to reduce yields 50 per cent prevailed and may have prevented differences in maturity from becoming evident. In height of plants at maturity the check and starchless classes averaged the same, while the dehulled and the germ classes were slightly shorter than the check. The weight of ears from the mutilated lots is less than from the checks and the number of ears to the plant less except in the dehulled class. The differences in yield per plant are small but seem directly attributable to the mutilation of the seed.

ROCKVILLE EXPERIMENTS.

The results obtained at the Yarrow Plant Introduction Field Station, Rockville, Md., in 1917, presented in Table I, show that the stands two weeks after planting varied from 44 per cent of a perfect stand from the dehulled seed to 91 per cent of a perfect stand from the check seed. The number of days from emergence to pollen shedding and the dates of ripening indicate that the development of the plants was retarded by the injuries to the seed. In height of plants, the dehulled and germ classes were shorter than the check and the starchless slightly taller. The average weight of ears from the mutilated seed is less than from the check in every comparison. The number of ears to the plant is greater in the mutilated classes than in the adjacent checks, with one exception. The average yields for each plant show reductions with but one exception, where one row from the germ class slightly outyielded the adjacent check row. The relative height of the plants from germs and those from entire seeds six weeks after emergence are shown in Plate II.

TABLE I.—*Data from the seed-mutilation experiments at Waco, Tex., Rockville, Md., and Rosslyn, Va., in 1917, 1918, and 1919.*

Locality and seed planted.	Ratio of actual to possible stand (per cent).	Time from emergence to shedding of first pollen (days).	Number of plants at harvest.	Ears harvested.				Yield per plant (pounds).	
				Weight (pounds).		Number.			
				Total.	Average.	Total.	Per plant.	As harvested.	Corrected to check.
At Waco, Tex., in 1917:[a]									
Check	98	78	39	8	0.210	38	0.976	0.205	0.180
Dehulled[b]	.....	.....	.....	.....	.....	.....	.....	.....	.....
Do	56	80	33	6	.182	33	1.000	.182	.170
Check	97	78	48	9	.191	47	.980	.187	.180
Starchless	95	78	38	6	.167	36	.948	.158	.....
Do	93	78	44	6	.171	35	.796	.136	c. 143
Check	99	78	49	9	.209	43	.878	.184	.180
Germs	57	80	42	5	.147	34	.810	.119	.....
Do	63	80	36	5	.161	31	.862	.139	c. 141
Check	99	78	48	7	.167	42	.876	.146	.180
At Rockville, Md., in 1917:[d]									
Check	88	64	49	33.7	.614	55	1.121	.689	.614
Dehulled	45	69	29	17.5	.500	35	1.206	.604	.....
Do	43	68	25	15.5	.517	30	1.154	.620	c. 576
Check	95	63	45	28.0	.667	42	.934	.622	.614
Starchless	79	65	43	17.0	.378	45	1.046	.395	.....
Do	79	65	47	18.0	.464	39	.830	.383	c. 445
Check	91	60	39	17.7	.680	26	.667	.454	.614
Germs	67	66	39	20.7	.543	38	.974	.531	.....
Do	51	66	46	18.0	.474	38	.826	.391	c. 504
Check	91	60	45	31.0	.586	53	1.177	.689	.614
At Rockville, Md., in 1918:[e]									
Check[f]	99	.....	42	.....	.....	.....	.....	.....	.....
Dehulled	78	.....	48	19.0	.453	42	.875	.396	.....
Do	73	.....	45	15.5	.443	35	.778	.345	c. 384
Check	98	.....	45	21.5	.615	35	.778	.478	.516
Starchless	95	.....	48	20.0	.540	37	.770	.417	.....
Do	95	.....	50	25.0	.569	44	.880	.500	c. 489
Check	99	.....	43	21.0	.568	37	.860	.489	.516
Germs	83	.....	42	16.5	.485	34	.810	.393	.....
Do	92	.....	45	18.5	.440	42	.934	.411	c. 402
Check	97	.....	44	25.5	.567	45	1.023	.580	.516
At Rosslyn, Va., in 1919:[g]									
Check	.....	65	48	47.7	.994	48	1.000	.994	.976
Dehulled	.....	68	46	41.1	.857	48	1.043	.894	.....
Do	.....	68	48	39.0	.780	50	1.041	.813	c. 898
Check	.....	66	48	41.3	.844	49	1.021	.860	.976
Starchless	.....	66	46	43.1	.918	47	1.021	.938	.....
Do	.....	66	49	39.4	.838	47	.960	.804	c. 913
Check	.....	66	47	47.2	.926	51	1.085	1.005	.976
Germs	.....	69	47	41.8	.836	50	1.065	.890	.....
Do	.....	69	46	40.0	.870	46	1.000	.870	c. 837
Check	.....	66	44	46.0	.940	49	1.114	1.045	.976

AVERAGES OF DATA FROM WACO, ROCKVILLE, AND ROSSLYN, 1917–1919.

Class of seed.	Time from emergence to shedding of first pollen (days).	Number of ears per plant.	Weight per ear (pounds).	Yield per plant (pounds).		Yield per acre (bushels).[h]
				As harvested.	Corrected to check.	
Check	68	0.961	0.585	0.571	0.572	57.2
Dehulled	72	1.012	.485	.504	.506	50.6
Starchless	70	.906	.506	.466	.497	49.7
Germs	72	.910	.495	.468	.467	46.7

[a] Seed planted Mar. 14, plants emerged Mar. 24, harvested Aug. 13, 1917.
[b] Stand destroyed by rodents.
[c] Average of the corrected yields of two rows.
[d] Seed planted May 18, plants emerged May 28, harvested Nov. 1, 1917.
[e] Planted June 6, plants emerged June 12, harvested Nov. 5 and 6, 1918.
[f] Through an error this row was not harvested.
[g] Seed planted May 17, plants emerged May 27, harvested Oct. 6, 1919.
[h] Calculated on the basis of a stand of 7,000 plants per acre and 70 pounds of ears per bushel.

In 1918 the experiment was repeated at the field station at Rockville, Md. The results, presented in Table I, show that the field stands two weeks after planting varied from 75 per cent of a perfect stand for the dehulled seed to 98 per cent for the check. No data were obtained on the time of pollen shedding, but judged from the moisture content of the ears at harvest the mutilation of the seed had retarded the maturity of the plant. The height of plants at maturity could not be correlated with the treatment of the seed. The average weight of ears in the mutilated classes was less than in the adjacent checks with one exception. The number of ears to the plant and the average yield for each plant were less than in the adjacent checks in most of the comparisons.

The experimental plantings at the Yarrow Plant Introduction Field Station in 1919 were destroyed by floods shortly after planting.

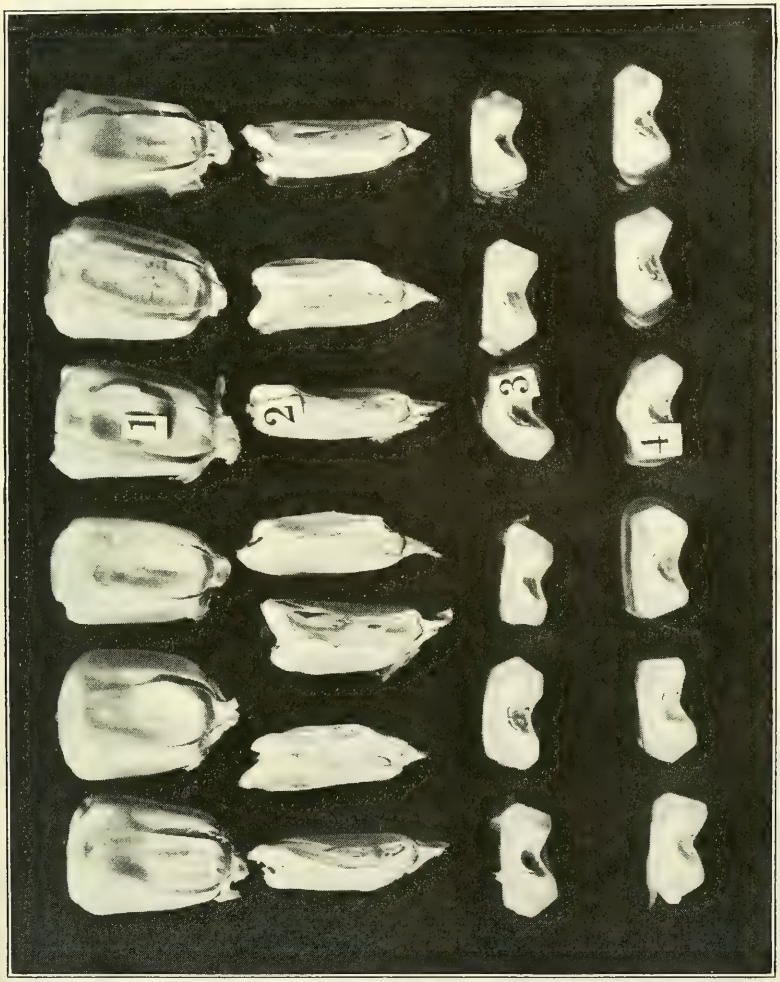
ARLINGTON EXPERIMENT.

The data obtained in the experiment at the Arlington Experimental Farm in 1919, presented in Table I, show that good stands were obtained. No counts were made, however, preceding the thinning. The dates of first pollen shedding were later in the mutilated-seed classes than in the check. The time of ripening did not appear to be materially affected. The general height of plants of the different lots at maturity did not noticeably differ. The weight of ears in the mutilated seed classes was less than from the adjacent checks except in one case. In number of ears to the plant, the dehulled class exceeded the adjacent checks in both comparisons, the starchless tied the check in one instance and was less in the other, and the germs were less than the checks in both cases. In average yield to the plant the mutilated classes were less than the adjacent checks with one exception.

EXPERIMENTS ON THE EFFECTS OF THE MUTILATION OF THE GERMS

In the experiments conducted in 1920 at the Arlington Experimental Farm the germs as well as the endosperms were mutilated. The seeds were cut into longitudinal and transverse sections. The longitudinal sections were made by cutting through from the germ side to the back of the kernel, dividing it approximately into halves (Pl. III, fig. 2); the cross sections were cut transversely to the long axis of the embryo, dividing the kernel into crown and tip portions. The crown portion contained much of the endosperm, part of the scutellum, and a small portion of the plumule (Pl. III, fig. 4); the tip contained a smaller amount of the endosperm, part of the scutellum, all of the radicle, and a portion of the plumule (Pl. III, fig. 3).

Preliminary investigations conducted in the laboratory were confined to germination tests and to observations during a short period of the early growth of the plants. In the field experiments, the



KERNELS AND SECTIONS OF KERNELS SHOWING THE CHARACTER OF THE MUTILATIONS TO THE EMBRYO AND ENDOSPERM.

Fig. 1, kernels with germs cut out and replaced; fig. 2, longitudinal half sections; fig. 3, transverse sections, tip portions; fig. 4, transverse sections, crown portions.

sectioned seeds and a third class, in which the germs were cut out and then replaced in the same kernels (Pl. III, fig. 1), were sown on fertile uniform soil and the plants grown to maturity in comparison with plants from entire seeds.

GERMINATION OF THE MUTILATED GERMS.

Two varieties of corn were used, United States Selection No. 230, a broad-kerneled yellow dent, and United States Selection No. 119, a smaller kerneled white dent. The germination tests were made in both sand and water germinators, but as the results from both were substantially the same only those made in sand are treated in detail. Of the yellow variety 38 kernels were sectioned longitudinally through endosperm and embryo, 39 kernels were cross-sectioned through endosperm and embryo, and 38 entire kernels were used as check seed. In the white variety 33 kernels were sectioned longitudinally, 25 were cross-sectioned, and 38 entire seeds were used as checks. In both the yellow and the white varieties the different classes of seed came from the same ear.

On February 1 the seeds were placed in a sand germinator and kept under favorable temperature and moisture conditions. Data obtained 10 days later on the plumule and root development are presented in Table II.

TABLE II.—*Data on the germination and the plumule and root development from entire and sectioned corn seeds at the Corn Laboratory, at Washington, D. C., in 1920.*

Variety.	Entire seeds.		Sections showing the development indicated.					
			Longitudinal sections.		Cross sections.			
					Tip portions.		Crown portions.	
	Number.	Per cent.	Number.	Per cent.	Number.	Per cent.	Number.	Per cent.
United States Selection No. 230:								
Total	38		76		39		39	
Germination		100		88.2		64.0		0
Plumule and roots—								
Development good			37	48.7	15	38.5	0	
Development weak			8	10.5	4	10.2	0	
Plumule, no development; roots, fair development			22	29.0	6	15.4	0	
Plumule and roots, no development			9	11.8	14	35.9	39	100
United States Selection No. 119:								
Total	38		66		25		25	
Germination		100		83.4		92.0		0
Plumule and roots—								
Development good			50	75.8	20	80.0		
Development weak			5	7.6				
Plumule, no development; roots, fair development					3	12.0		
Plumule and roots, no development			11	16.6	2	8.0	25	100

The use of the term "good development" in Table II is entirely relative; in no instance were the plumules and roots from the sections equal in growth and vigor to those from the entire seeds. The coleoptiles and first leaves had a torn and ragged appearance, as a result of the mutilation of the seeds. There was no development of the plumule from the crown sections, but in some there were indications of growth or viability in the plumule tips contained in these sections, there was a slight swelling of the tissues and a tendency to turn yellowish green in color. This attempt to grow could not, or at least did not, persist long enough to lead to any development of the plumule or to show any tendency toward a regeneration of the roots.

Similarly, in the tip sections that showed no plumule but a fair development of the root system there did not appear to be any tendency toward a regeneration of the plumule. In the longitudinal sectioning of the seeds, portions of the plumule and of the radicle were left in each section. In the laboratory 45 seedlings showing plumule and root development were obtained from 38 seeds sectioned longitudinally in one variety and 55 seedlings showing plumule and root development from 33 seeds in another variety. This is not brought out in Table II, as the percentages are based on the total number of sections and not on the total number of seeds.

GROWTH AND SEED PRODUCTION OF THE MUTILATED GERMS.

Two varieties were used in the field experiments, United States Selection No. 182, a white dent variety, requiring about 130 to 140 days to ripen, and United States Selection No. 193, a yellow flint variety, requiring about 110 to 120 days to ripen. On May 12 entire kernels, longitudinal sections, cross sections, and kernels out of which the germs had been cut and then replaced in the same kernels were sown at the Arlington Experimental Farm, Rosslyn, Va. The injured classes were sown thickly, 15 to 20 sections to a hill. The crown and tip portions of the cross sections were not separated, but in view of the results obtained in the laboratory it seems certain that the plants in this class grew from the tip portions. The data obtained on the field experiments are shown in Table III.

In United States Selection No. 182 the plants from the longitudinal half-sections were slightly higher in average production to the plant, weight of ear, and number of ears to the plant than the plants grown from the entire seeds; the plants from the other two classes of injured seed were inferior to those from entire seeds. The plants from the cross sections were the least thrifty and were lowest in productiveness, weight of ear, and number of ears to the plant.

TABLE III.—*Comparison of the growth and yield of corn plants grown from entire and sectioned seed at the Arlington Experimental Farm, Rosslyn, Va., in 1920.*[a]

Variety.	Row No.	Date of—		Number harvested.				Production (pounds).			Number of nodes above ground.	Height (feet).	
		First pollen shedding.	First silks.	Plants.	Suckers.	Ears.	Ears per plant.	Ears.	Per plant.	Average per ear.		Plants.	To ear.
United States Selection No. 182, white dent:													
Entire kernels ..... 10 hills	102a	Aug. 1	Aug. 2	20	3	22	1.10	20.0	1.000	0.910	16	9 to 10	3 to 4½
Half sections (longitudinal) ..... 10 hills	102b	Aug. 4	Aug. 5	14	3	16	1.14	16.0	1.140	1.000	16	9 to 10	3 to 4½
Cut out and replaced germs ..... 10 hills	102c	Aug. 5	Aug. 6	13	2	14	1.08	12.0	.924	.858	16	9 to 10	3 to 4½
Half sections (cross) ..... 10 hills	102d	Aug. 6	Aug. 7	15	0	16	1.07	11.0	.734	.688	16	9 to 10	3 to 4½
United States Selection No. 193, yellow flint:													
Entire kernels ..... 10 hills	103a	July 22	July 23	20	35	23	1.15	15.0	.750	.652	11 to 14	6 to 8	1½ to 3
Half sections (longitudinal) ..... 10 hills	103b	July 25	July 28	20	23	28	1.40	13.8	.690	.493	10 to 12	6 to 8	1½ to 3
Cut out and replaced germs ..... 10 hills	103c	July 26	....do....	18	20	25	1.39	13.2	.734	.528	10 to 12	6 to 8	1½ to 3
Half sections (cross) ..... 10 hills	103d	July 31	Aug. 3	19	2	15	.79	5.8	.305	.305	10 to 12	6 to 8	1½ to 3

[a] Date of seeding May 12, harvested October 11, 1920.

The plants from the mutilated seeds were shorter and weaker in appearance than those from the entire seeds during the first six or eight weeks of growth. Later, the differences in height largely disappeared, and when harvested the different lots were approximately of the same average height. In general, the plants from the entire seeds were the most vigorous throughout the season, although there were exceptional plants from the injured seeds that equaled them.

In United States Selection No. 193 the plants from the injured seeds were inferior to the plants from the entire seeds in average production to the plant and in average weight of ear but surpassed the check plants in number of ears to the plant except those from the cross sections, which were inferior in every respect. The number of nodes above ground was slightly less in the plants from the injured seeds than those from the entire seed.

The data on the yields and prolificacy shown in Table III have been presented as evidence of the extent to which plants from seeds so severely mutilated could recover to a condition of normal growth and reproduction rather than as a comparison of the productivity of the different lots of seed.

SUMMARY.

The effects of the mutilations of the seed coats and endosperms may be summarized as follows:

(1) The stands were less than from the check seed. The poorest stands were obtained from the dehulled seed. This was not due to decreased viability, but evidently to weakened ability to withstand field conditions.

(2) Seedlings from mutilated seed in general were smaller than those from the check seed. The least difference was between the starchless class and the check. In some instances the seedlings from the two classes were not distinguishable in size and vigor. Seedlings from the dehulled class were noticeably smaller than those from the check seed. Seedlings from the germs were much smaller, more slender, and had narrower leaves than those from the check seed.

(3) The height of plants at maturity was not definitely affected, and it bore no consistent relation to the height of the check plants.

(4) The development of the plants was retarded, pollen shedding and ripening, in general, being later than in the checks.

(5) The average number of ears to the plant was reduced. The only exception was the dehulled class, which exceeded the check in the general average.

(6) The average weight of ears and the yield of the plant were less than in the checks. The degree of reduction was fairly consistent with the extent of the mutilations.

(7) The reductions in yield were equivalent to 7 to 10 bushels to the acre.

A summary of the results of the experiments with mutilated germs follows:

(1) The entire embryo was not essential to germination and development into normal plants.

(2) Normal plants were grown from seeds that had been cut into half sections through both the embryo and endosperm.

(3) In the laboratory 100 seedlings showing plumule and root development were obtained from 71 seeds sectioned longitudinally.

(4) The tip portions of the cross sections developed complete plants, and there was no development from the crown portions.

(5) There was no regeneration of one organ from another.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 1012

Contribution from the Bureau of Animal Industry
JOHN R. MOHLER, Chief

Washington, D. C. PROFESSIONAL PAPER April 17, 1922

THE DEATH CAMAS SPECIES, ZYGADENUS PANICULATUS AND Z. ELEGANS, AS POISONOUS PLANTS.

By C. Dwight Marsh, *Physiologist in Charge of Investigations of Stock Poisoning by Plants*, and A. B. Clawson, *Physiologist, Pathological Division.*

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PURPOSE AND SCOPE OF PAPER.

In Bulletin 125, United States Department of Agriculture, page 35, the following statement was made with regard to the comparative toxicity of different species of Zygadenus:[1]

In the course of the experiments four species of Zygadenus were used—*Z. venenosus*, *Z. elegans*, *Z. paniculatus*, and *Z. coloradensis*—by far the greater part of the work being done with *Z. venenosus*. The number of experiments with *Z. elegans* and *Z. paniculatus* was very small, and the material, especially in the case of *Z. paniculatus*, had been shipped a long distance, so that there was some question of the water content of the plant. Apparently, however, *Z. elegans* and *Z. paniculatus* do not differ materially in toxicity from *Z. venenosus*. *Z. coloradensis*, however, produced no toxic effects whatever, with the exception of slight symptoms in one sheep, although the plant was fed in quantities several times as great as the toxic dose of *Z. venenosus*.

It is evident that in the feeding of cattle with *Z. coloradensis* at Mount Carbon in 1909, the results of which are given in Table I, the quantities fed were too small to produce results, even if the plants were as poisonous as *Z. venenosus*. In the experiment of 1910, however, a large quantity was fed, and sufficiently large quantities in single days to produce symptoms of poisoning if the plant were as toxic as *Z. venenosus*.

Most of the work reported in Bulletin 125 was on the species of Zygadenus growing in the Yellowstone Valley, Montana, which

[1] Zygadenus, or Death Camas, by C. Dwight Marsh, A. B. Clawson, and Hadleigh Marsh, Bulletin 125, United States Department of Agriculture, 1915.

at that time was determined by systematic botanists as *Z. venenosus*. Later systematic work has shown that the species used was not the true venenosus, but was *Z. gramineus*. Of the other species used, *Z. elegans* and *Z. coloradensis* are so closely allied that they are considered by many botanists as not specifically distinct. There is no question, however, of the specific distinction between *Z. gramineus*, *Z. elegans*, and *Z. paniculatus*. From further work it seemed probable that there was a much greater difference in toxicity of the species than was apparent at the time Bulletin 125 was published, and it became a matter of considerable importance to determine the comparative toxicity of the different forms.

All these species are so closely allied that they are not likely to be separated by anyone who has not a fairly good knowledge of botany. It follows, of course, that ordinarily all these forms are grouped under the term "death camas" without perception of the difference between the species. It is a matter of much scientific and practical interest to know how they differ.

Z. paniculatus is the most widely distributed and is the most common form of death camas in the intermountain region and in part of the western slope. *Z. elegans* is not so abundant but is the common species on the higher mountain ranges of the West. Both *Z. elegans* and *Z. paniculatus* grow in considerable quantity in the neighborhood of the Salina Experiment Station, Utah, where a somewhat extended study of the plants has been made. The proof that these species are either more or less toxic than *Z. gramineus*, which grows in Montana, would be of very great practical importance to the stockmen who use the ranges where these plants are found.

The experimental work was conducted on the same general lines as the work in Montana, and the results have proved to be of considerable importance. Still further work is necessary on the species of this genus, but the results obtained regarding these two species are definite and conclusive. All the work here reported was done on plant material collected in Utah. Inasmuch, however, as experience with poisonous plants indicates that difference in locality has little effect on the degree of toxicity, the conclusions reached here undoubtedly will apply equally well to these species wherever they may be found. It may be added that *Zygadenus intermedius*, on which work has been done by other authors, is considered by systematists as being identical with *Zygadenus gramineus*.

ZYGADENUS PANICULATUS.

DESCRIPTION AND DISTRIBUTION OF THE PLANT.[2]

Zygadenus paniculatus, shown in Plate I, is an erect perennial herb with leafy stems arising from fibrous-coated bulbs. The linear leaves

[2] The description of *Z. paniculatus* and its distribution was prepared by W. W. Eggleston, of the Bureau of Plant Industry. Mr. Eggleston has made a detailed study of the genus Zygadenus.

are scythe-shaped, all sheathing, roughish on both sides, rather thick, 6 to 12 inches long, and one-third to two-thirds of an inch wide. The stems are stout, erect, and 1 to 2½ feet high. The flowers are in panicled racemes, and consist of six segments with membranous bracts; the upper segments are deltoid, acute, or acuminate, with a short claw and glands at base not definitely margined. The flower segments are one-sixth to one-fourth of an inch long and are free from the 3-celled ovary. The ovary is cylindrical and one-half to 1 inch long. The stamens are raised above the flower segments.

This plant is largely confined to the Great Basin. (Fig. 1.) Its known range is from the British Columbia line in the Cascades south, in Washington, along the eastern side of the Cascade Range to northwestern California, where for a distance it crosses to the western side of the Sierra Nevadas. It follows the eastern slope of the Sierra Nevada Mountains to the southern extremity of Nevada. It ranges eastward across southern Washington and central Idaho to western Montana, thence across southwestern Wyoming to northeastern New Mexico and northern Arizona. It ascends on the British Columbia line to about 7,000 feet and in the Wasatch Mountains to about 8,500 feet. In California it is found above 2,700 feet. Its best habitat is the dry gravelly ridges of the juniper-piñon-oak belt.

FIG. 1.—Distribution of *Zygadenus paniculatus*.

Because of the wide range of conditions under which the plant grows, its time of flowering varies. It is said to blossom in California from April to June. Near the Salina Experiment Station, Utah, where it grows at an altitude of more than 8,000 feet, it does not blossom until June and is in seed the last of the month.

EXPERIMENTAL FEEDING.

In 1919, 1920, and 1921, 7 experimental feedings of *Z. paniculatus* were made on cattle and 44 on sheep. Table 1 gives a summary of these experiments.

TABLE 1.—*Summary of feeding experiments with Zygadenus paniculatus, 1919, 1920, and 1921.*

Animal.		Date of feeding.	Method of feeding.	Part of plant used.	Weight of plant estimated as green plant for 100 pounds of animal.	Result.	Place and date of plant collection.	Remarks.
Designation.	Weight.							
Sheep Nos:	*Pounds.*	*1919.*			*Pounds.*			
519	59	June 10	Balling gun	Leaves and bulbs	0.627	Not sick	Ephraim, Utah, June 9, 1919.	10 per cent allowed for loss by evaporation.
528	75	June 11	do	do	1.175	Very sick	do	20 per cent allowed for loss by evaporation; probably more should be allowed.
530	80	June 13	do	Leaves, stems, and buds	1.096	Sick	Flat Top, near Salina, June 12, 1919.	10 per cent allowed for loss by evaporation.
520	86	June 13 to 15	Fed in hay	do	(1)	Not sick	do	Refused to eat.
555	92	June 14	Balling gun	do	1.261	Sick	do	20 per cent allowed for loss by evaporation.
540	86	June 16	do	Leaves, stems, buds, and bulbs	1.761	do	do	40 per cent allowed for loss by evaporation. Vomited part of material fed.
Cattle No:								
826	386	June 21	Fed in hay	Leaves, stems, and immature flowers.	1.295	do	Flat Top, June 19, 1919.	
Sheep Nos:		1920.						
564	77.5	June 9 to 15	do	do	.284	do	Flat Top, June 8 and 11, 1920.	
579	69	June 15 to 18	do	do	(1)		Flat Top, June 11, 1920.	
578	90.5	June 15 to 19	do	do	1.150±	Sick	do	
581	67	June 18	Balling gun	Leaves, stems, flowers, and young fruit.	1.010	Not sick	Bear Valley, Utah, June 16, 1920.	
521	103	June 20 to 23	Fed in hay	Leaves, stems, and old flowers	.728	do	Flat Top, June 19, 1920.	
554	115	do	do	do	1.301	do	do	
500	135.5	June 20 to 26	do	do	.738±	do	do	
583	83	June 21	Balling gun	Leaves, stems, flowers, and young fruit.	1.505	Sick	Bear Valley, Utah, June 16, 1920.	
586	132.5	June 22 and 23	Fed in hay	Leaves, stems, and old flowers	(2)		Flat Top, June 19, 1920.	
590	86	June 23	Balling gun	Leaves, stems, flowers, and young fruit.	2.077	Sick	Bear Valley, June 16, 1920.	
591	100.5	June 25 to 28	Fed in hay	Leaves, stems, and old flowers	(2)		Flat Top, June 24, 1920.	

592	123	do	do	do	(2)		Flat Top, June 19 and 24, 1920.	
594	95	June 25 to 29	do	do	2.105±	Not sick	Flat Top, June 24, 1920.	
593	68.5	June 26	Balling gun	do	1.323	Sick	do	
599	93	June 29	do	Leaves, stems, and young fruit	1.543	Symptoms	Flat Top, June 28, 1920.	
598	100.5	June 30 to July 3.	Fed in hay	do	.75±	Not sick	do	
602	79.5	July 1	Balling gun	do	1.764	Sick	Flat Top, June 30, 1920.	
604	120	July 2 to 4	Fed in hay	do	.833±	Not sick	do	
605	101.25	July 3	Balling gun	do	1.984	Sick	do	
609	83	July 8	do	Leaves and stems	1.984	do	Flat Top, July 7, 1920.	Fruits had been removed.
569	92	July 9	do	Fruit heads	.661	Very sick	do	
575	69.5	July 10	do	Leaves and stems	2.862	Sick	do	
607	103	August 4	do	Fruit heads nearly fully developed.	.358	Not sick	do	
609	87	August 5	do	do	.620	Sick	do	
583	102	August 26	do	Seed (ripe and dry)	3.070	Very sick	Between Cove Fort and Beaver, Utah, July 23, 1920.	Figured as dry seed.
Cattle Nos:								
874	325	June 12 and 13.	Fed in hay	Leaves, stems, and flowers	.468	Weakness	Flat Top, June 11, 1920.	Loss in drying about 82 per cent. About 1.5 pounds eaten by animal.
867	379	June 15 to 20	do	do	.659	Salivation and weakness.	do	Sick after eating 0.264 pound in 1 day. Symptoms continued for 6 days.
870	382	June 20 to 26	do	Leaves, stems, and old flowers	5.759	Weakness	Flat Top, June 19 and 24, 1920.	Symptoms after eating about 0.8 pounds of Zygadenus.
861	420	July 3 and 4	do	Leaves, stems, and young fruit	.738	Salivation	Flat Top, June 30, 1920.	Not all eaten when symptoms appeared.
863	496	do	do	do	1.109	Vomiting	do	Sick after eating about 0.7 pound.
Sheep Nos:		1921.						
582	108.5	July 13	Balling gun	Leaves, stems, and flowers	1.323	Symptoms	Flat Top, June 15, 1921.	Dry plant fed, estimated as green.
612	98	July 18	do	do	1.323	Sick	Flat Top, June 25, 1920	Do.
617	118	July 19	do	do	2	do	do	Do.
628	109.5	August 2	do	do	2.1	do	do	Do.
629	115	August 4	do	do	2.3	do	do	Do.
644	90.5	August 15	do	do	2.5	Death	do	Death perhaps due to pneumonia.
647	88	August 22	do	do	2.5	Very sick	do	Dry plant fed, estimated as green.

[1] None eaten. [2] Little, if any, eaten. [3] Dry weight.

TYPICAL CASE OF SHEEP 602.

Sheep 602 was a yearling ewe, weighing at the time of the experiment 71.5 pounds. It was taken into the corrals on June 29, 1920, and kept under observation until the experimental feeding was undertaken, on July 1.

On July 1, at 11.15 a. m., the animal was given by balling gun 1.764 pounds, per 100 pounds of animal, of leaves, stems, and young fruit of *Z. paniculatus*. At 2.30 p. m. the animal was frothing at the mouth, and in walking reeled from side to side. At 2.35 p. m. the weakness was most pronounced in the hind legs. This weakness gradually increased and at 7.40 p. m. the animal, in walking, not only staggered but dragged the hind feet. The condition remained the same during the evening. The next day, July 2, at 6.38 a. m., the animal was still frothing at the mouth and apparently somewhat nauseated, although it seemed somewhat stronger than during the preceding evening. During the day its condition did not change materially. It was quiet and depressed and weak, but not very sick. The last observation of the day was made at 4.15 p. m.

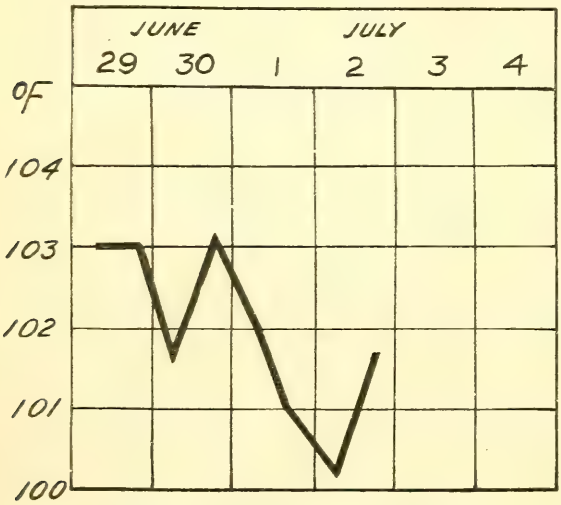

FIG. 2.—Temperature curve of Sheep 602.

On the morning of July 3 the animal seemed to be entirely recovered. The temperature curve is shown in text figure 2. While there were variations in the pulse and respiration, the changes were not significant.

Sheep 602 may be considered as a fair type of animals which are not very sick.

TYPICAL CASE OF SHEEP 569.

Sheep 569 was a 2-year-old wether, weighing 85.5 pounds at the time of the experiment. It was taken from the pasture into the corrals on the morning of July 8, 1920. At this time the temperature was 103° F., pulse 88, respiration 32. The sheep was observed again at night, and on the morning of July 9. At 9.35 a. m., July 9, the temperature was 103° F., pulse 96, respiration 24. At 2 p. m. the animal was given by balling gun 0.661 pound, per hundredweight of animal, of fruit heads of *Z. paniculatus*. At 4.37 p. m., the animal

was found to be very sick and in some pain, with irregular respiration. There was a pause after the inspiration, followed by a somewhat forcible expiration. The animal was weak and soon lay down. At 4.46 p. m., the temperature was 98.4° F., pulse 96, respiration 28. The pulse was fairly strong and regular. The respiration continued as before. At this time the sheep was frothing at the mouth, was much depressed, and showed weakness in the hind legs. A little later the respiration was found to be very rapid, being approximately 200. At 5.32 p. m., the animal was down, evidently had been struggling, and was unable to rise. Plate II, figure 1, shows the position the animal assumed at this time. From then until about 6 p. m., its condition remained practically unchanged. The temperature at 5.34 p. m. was 99.4° F., and the respiration 40. Most of the time the animal was fairly quiet but unable to rise. At 5.57 p. m., it was able to get up on its feet, although still very weak. Plate II, figure 2, shows the attitude assumed at this time. The weakness seemed most pronounced in the forelegs. About 6 p. m. it went down because of weakness and almost immediately got up again, the weakness, as before, being most pronounced in the forelegs. From 7.20 until 11.13 p. m. it was lying down quietly, most of the time apparently unable to rise. At 11.13 p. m. it was breathing heavily and rather noisily at the rate of 20 a minute.

On July 10, at 6.30 a. m., it was in about the same position as during the preceding evening. Plate II, figure 3, shows its attitude at this time. At 8 a. m., while still lying down, it was found to have moved across the pen. At 8.40 a. m., when disturbed it attempted to get upon its feet, but was unable to lift the body on the forelegs. At this time the temperature was 99.3° F., pulse 112, and respiration 24. These observations were taken just following an attempt to rise. After lying quietly, the pulse was about 100. The sheep at this time was in a semicomatose condition, with the eyes half closed, but roused if approached. The condition remained much the same during the rest of the day, and the evening. The picture Plate II, figure 4, taken at 2.50 p. m., shows very well the condition of the animal. The coma was very pronounced during this period. At midnight the animal commenced to kick and went into a position of opisthotonos, at the same time gasping. Following these spasmodic movements, which could hardly be called convulsions, its mouth was opened during the expirations.

On July 11, at 7.30 a. m., it was found lying much as at midnight, but breathing more easily. At 10.35 a. m., the temperature was 99.7° F., pulse 120, respiration 44. The pulse was weak and variable, and the respiration somewhat labored. A little later the respiration was too fast to count. The condition remained the same during the forenoon and evening. At 4.15 p. m. and at 5 p. m., it was

given hypodermically 5 c. c. of gin, which seemed to have an immediate but temporary effect in strengthening the action of the pulse. No change was noticed during the evening, except that at 11.25 p. m., the pulse was found to be distinctly stronger than earlier in the evening.

On July 12, at 8.30 a. m., the temperature was 100.6° F., pulse 116, and respiration 16. The pulse was very weak, while the respiration was deep and regular. The animal appeared brighter than during the preceding evening, but was still lying down. At 10.45 a. m., the sheep was raised up, and drank 3 or 4 quarts of water. It was able to hold itself up for two or three minutes, but soon lay down again. The animal drank again at 11.35 a. m., and attempted to get up on its feet, but was unable to do so. At 3.30 p. m., it was raised up and drank more water. The temperature at this time was 100.6° F., pulse 120, and respiration 12. At 5 p. m., it was offered some green forage, and ate readily. The condition continued unchanged during the evening.

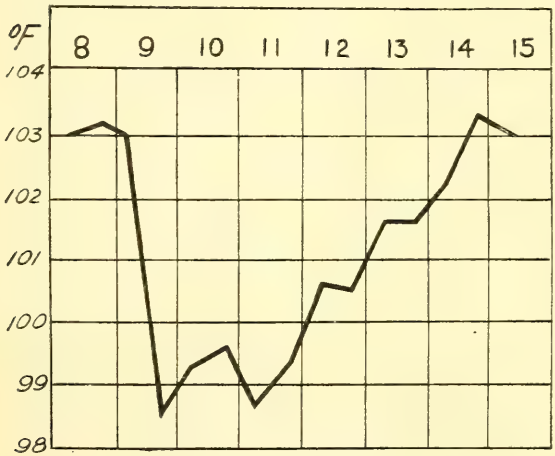

FIG. 3.—Temperature curve of Sheep 569.

On July 13, at 7 a. m., the sheep was raised up on its feet and held, and then it became able to stand alone. It was unable, however, to walk without falling. The legs of the left side seemed weaker than those of the right. This perhaps was due to the fact that during the period it was lying down it lay upon the left side. At 4.11 p. m., the temperature was 101.6° F., pulse 120, respiration 164. The pulse was fairly strong and regular. The respiration was short but regular. At this time the animal was on its feet although still very weak. It was able to walk out into a large corral to drink with the other sheep.

During the day, July 14, the temperature of the animal was higher, being 103.3° F. at 4.35 p. m. The pulse was strong and regular and the respiration became more normal. The sheep was quite strong and able to get about and eat.

On the morning of July 15 the animal seemed to have entirely recovered, and was turned into the pasture with the other sheep. Text figure 3 shows the curve of temperature during the illness of the animal.

ZYGADENUS PANICULATUS. PLANT WITH BULB AND FLOWERS.

FIG. 1.—SHEEP 569 AT 5.32 P. M. JULY 9, WHEN POISONED BY ZYGADENUS PANICULATUS,

FIG. 2.—SHEEP 569 AT 5.57 P. M. JULY 9, ABLE TO STAND, BUT VERY WEAK.

FIG. 3.—SHEEP 569 AT 6.30 A. M. JULY 10, SHOWING EXTREME WEAKNESS.

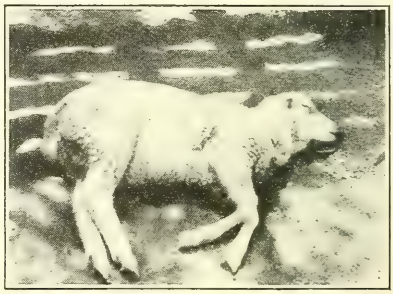

FIG. 4.—SHEEP 569 AT 2.50 P. M. JULY 10, IN CONDITION OF COMA.

FIG. 5.—CATTLE 863 POISONED BY ZYGADENUS PANICULATUS, IN ACT OF VOMITING.

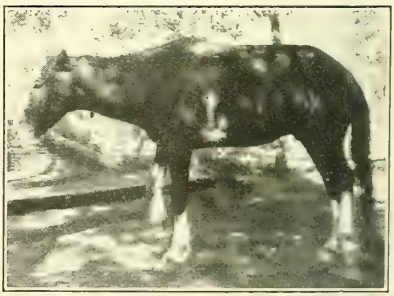

FIG. 6.—HORSE 137 POISONED BY ZYGADENUS PANICULATUS, THE ATTITUDE SHOWING EXTREME DEPRESSION AND DISCOMFORT.

TYPICAL CASE OF CATTLE 863.

Cattle 863 was a steer in good condition, weighing 457 pounds at the beginning of the experimental feeding. It was brought into the corrals on the afternoon of June 30, 1920, and received no feed before the experimental feeding of *Z. paniculatus* was commenced. On July 3, at9 .50 a. m., it was fed leaves, stems, and young fruit of *Z. paniculatus,* and received another feed at 5.15 p. m. the same day. At 9.10 a. m., July 4, it had eaten of the material 1.109 pounds per hundredweight of animal, and refused to eat more. At this time there were no definite symptoms of toxic effect except the refusal to eat. At 5.12 p. m. it was found much salivated and commenced to vomit. This vomiting continued at frequent intervals for about one hour. Plate II, figure 5, shows the animal in the act of vomiting. No further symptoms were noted except the rather unusually low temperature of 99.9° F. at 7.25 a. m., July 5. At this time the general appearance of the animal was good, and it was turned into the pasture as practically recovered. Text figure 4 shows the curve of temperature, indicating a depression as in the other cases.

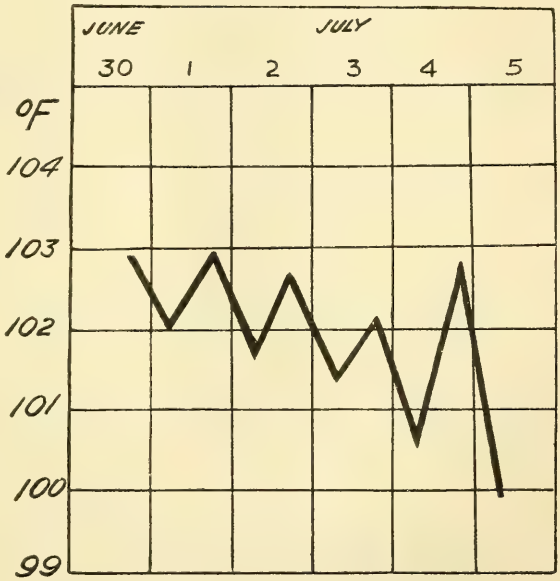

FIG. 4.—Temperature curve of Cattle 863.

ACCIDENTAL CASE OF HORSE 137.

No experiments in feeding the plant to horses were made. An accidental case, however, occurred which was of considerable interest and should perhaps be recorded, since little definite evidence has ever been obtained regarding the effects of Zygadenus upon this class of animals.

Horse 137 was one of the saddle horses used at the station. On July 6, 1920, at 8.15 a. m., it was noticed that this animal was much depressed and salivated, and saliva scattered about the corral showed that this condition of salivation had continued for some time. While this animal was a so-called gentle horse, it never readily per-

mitted itself to be bridled or handled in any way, except when penned up at one corner of the corral. On this morning it could be approached easily and did not object to handling. The respiration was faster than normal, and at intervals retching was observed. In searching for the cause of the illness it was found that the horse had eaten some of a mixture of *Z. paniculatus* and hay that had been thrown into the corral. It was impossible to tell how much he had eaten, so that there was no means of telling what the dosage of the plant had been. The animal showed some abdominal discomfort, and at 9.30 a. m. he was pawing the ground in a manner that indicated some pain. His respiration was about 60 a minute. During the forenoon this condition continued, with prolonged spells of retching, succeeded by profuse salivation. The animal did not stagger or show any unusual weakness. This condition continued during the forenoon and part of the afternoon, but by 4.30 p. m. he had practically recovered.

As the horse was sick when first seen in the morning it was impossible to tell how long the illness continued, but it must have been at least six hours and perhaps somewhat longer. The case is interesting because the symptoms were entirely comparable with those exhibited by sheep and cattle, but did not continue to the stage of weakness. Plate II, figure 6, shows the attitude which the horse assumed during the acute stage of the illness.

DISCUSSION AND RESULTS.

SYMPTOMS.

Salivation.—Salivation appeared in all the cases observed during 1919 and 1921, and was the most distinctive symptom. It occurred in 1920 in 3 of the 5 cattle cases, and in 11 of the 13 sheep cases. Salivation in most cases is the first definite evidence of the effect of the plant. This, of course, can not be considered as an especial characteristic of Zygadenus poisoning, because it occurs in a great many forms of intoxication from plants.

Nausea.—Nausea was exhibited in all the cases in 1919. It was common in the experimental animals of 1920 and 1921, but did not appear in all cases, probably because the sickness was not always very pronounced. Sometimes it was indicated only by regurgitation. In one of the cattle and six of the sheep it resulted in vomiting.

Weakness.—Muscular weakness occurred in 4 of the 5 cases of 1919, in 3 of the 13 sheep, and 2 of the 5 cattle in 1920, and in 6 of the sheep in 1921. In all but one of the cases this weakness was most pronounced in the hind legs and resulted in a characteristic staggering gait. In Sheep 569, which was very sick, and in Sheep 641, which died, this weakness was so pronounced that they were unable to stand. In Sheep 583 and Cattle 784 weakness was the only symptom noted except a depression in temperature. This is well shown in Plate II, figures 1 to 4, in the case of Sheep 569.

Temperature.—In the experimental work of 1919, Cattle 826 was the only case in cattle that showed a depression of temperature. Of the 4 sheep, 3 had a low temperature. In 1920, the 5 head of cattle exhibited a lowered temperature, and of the 13 sheep all but 2 showed the same effect of the plant. In 1921, 4 of the 6 sheep had a lower temperature. This condition of temperature was distinct, but ordinarily the temperature was not very low. The lowest was 98.4° F., which was noted in two cases. One observation of 98.8° F. was made, two of 99° F., and one of 99.6° F. More commonly the temperature did not go below 100° F. and could not be considered as distinctly subnormal. There was, nevertheless, in most cases, a definite lowering of temperature. This is shown in the temperature curves of Sheep 602, Sheep 569, and less markedly in Cattle 863. In the case of Sheep 569 a number of temperatures were recorded besides those of morning and night shown in the diagram, but these additional observations did not alter the character of the curve.

In the work carried on at Greycliff, Mont., on the Zygadenus which is stated in Bulletin 125 to be *Z. venenosus*, and which we are now informed was *Z. gramineus*, it was noted that a depression in temperature sometimes appeared when no other symptoms were seen. It was questioned whether the same phenomena might not occur in the cases receiving *Z. paniculatus*. The only case of this character was Sheep 594, which in 5 days, receiving 2.105 pounds, had no noted symptoms except a lowering of temperature.

In the discussion of the Montana work, in Bulletin 125, the statement was made that a low temperature could hardly be considered as diagnostic of Zygadenus poisoning. The additional work which has been carried on with *Z. paniculatus* shows that while one or a few observations are not diagnostic, if a fairly complete record is made after the feeding of the plant to the animal, this record when plotted is pretty certain to indicate whether any toxic effect has been produced.

Pulse.—The pulse rate in the sick sheep varied from 52 to 220. The rate of 220 was shown by Sheep 644, which had pneumonia. In the sick cattle it varied from 48 to 210. This latter figure, however, was observed in an excited animal before the feeding of the plant. The highest rate after the feeding of the plant was 84. In 2 or 3 of the sheep the pulse rate was slightly higher during the depression of temperature, but in most cases the curve of the pulse followed rather closely the curve of temperature, being low when the temperature was low and rapid when the temperature was high. In some cases it was weak and in some intermittent.

Respiration.—There was some irregularity in respiration, but in general the rate of respiration varied, much like that of the pulse. It was noted in Bulletin 125, in regard to *Z. gramineus*, that there

was a very high rate in the acute stages of the sickness. That this symptom did not appear in the *Z. paniculatus* cases may be explained by the fact that most of the animals were not very sick; that is, the sickness could not be considered as acute at any time. It did occur, however, in Sheep 569, which was very sick. This animal, too, as well as Sheep 644 and 647, exhibited labored breathing. It may be remarked, in this connection, that under normal conditions there is frequently great variation in the respiration of sheep; under excitement the rate may be temporarily very high.

Other symptoms.—Some of the animals groaned and gnashed their teeth during the sickness, and Sheep 569 and Sheep 647 went into a condition of coma. Coma is also a frequent symptom in the animals made very sick by *Z. gramineus*, as shown in Bulletin 125.

In general, the symptoms were practically identical with those seen in *Z. gramineus* cases, but less pronounced, because of the smaller toxicity of *Z. paniculatus* as compared with *Z. gramineus*.

DURATION OF SYMPTOMS.

The following table shows the time that elapsed between the first and last observed symptoms. It should be noted that this probably does not indicate accurately the entire time during which the animals were sick, because in many cases the sickness persisted for a greater or less time after the last note was made.

TABLE 2.—*Duration of symptoms.*

Animal.	Method of feeding.	Time sick.	Animal.	Method of feeding.	Time sick.
1919.			1919		
Sheep Nos.:			Cattle No.:		
528	Balling gun	67 hours 5 minutes. ±	826	Fed in hay	Do.
530	do	20 hours 33 minutes ±			
555	do	27 hours 40 minutes ±	1920.		
540	do	19 hours 8 minutes. ±	Cattle Nos.:		
			874	do	One observation.
1920.			867	do	96 hours.
Sheep Nos.:			870	do	60 hours.
528	do	67 hours 5 minutes.	861	do	Salivated; one observation.
530	do	20 hours 33 minutes.			
555	do	27 hours 40 minutes.	863	do	½ hour.
540	do	19 hours 8 minutes.			
564	Fed in hay	24 hours.	1921.		
578	do	Do.	Sheep Nos.:		
583	Balling gun	7 hours.	582	Balling gun	One observation.
590	do	36 hours.	612	do	16 hours 18 minutes.
593	do	3 hours.	617	do	23 hours 33 minutes.
599	do	Do.	628	do	42 hours 50 minutes.
602	do	26 hours.	629	do	49 hours 16 minutes.
605	do	29 hours.	644	do	Death; sick 72 hours 43 minutes.
569	do	96 hours.			
575	do	24 hours.	647	do	72 hours 21 minutes.
609	do	60 hours.			
583	do	72 hours.			

The average in all the force-fed sheep cases, 25 in number, was 36 hours and 2½ minutes. The minimum was a single observation in Sheep 582, and the maximum was 4 days in Sheep 569. Sheep 569 644, and 647 were very sick, but it is not at all clear that in other

cases the duration of illness was correlated with the severity of the attack.

Of the cattle it should be noted that on 874 and 861 only a single observation was made, so that the sickness can not be considered as continuing an appreciable length of time. Of the other cattle, the average time of duration of illness was 57 hours and 7 minutes, while the shortest period was 30 minutes, and the longest 4 days.

TIME REQUIRED TO PRODUCE SYMPTOMS.

The cattle and two of the sheep were given the Zygadenus in hay, so that the feeding extended over a considerable period of time, and it would be impossible in these cases to determine the time between the feeding and the appearance of symptoms. This can be done, however, in the animals that were given a forced feeding by the balling gun. The following table shows the time elapsed in the case of these sheep.

TABLE 3.—*Time elapsed between feeding of plant and development of symptoms.*

Animal.	Time elapsed before symptoms appeared.	Animal.	Time elapsed before symptoms appeared.	Animal.	Time elapsed before symptoms appeared.
1919.		1920.		1921.	
Sheep Nos.:		Sheep Nos.:		Sheep Nos.:	
528	3 hours.	593	5 hours 30 minutes.	582	4 hours.
530	1 hour 47 minutes.	599	3 hours.	612	4 hours 44 minutes.
555	2 hours 33 minutes.	602	Do.	617	2 hours 5 minutes.
540	2 hours 12 minutes.	609	55 minutes.	628	50 minutes.
		609	3 hrs.	629	1 hour 38 minutes.
1920.		569	2 hours 15 minutes.	644	1 hours 42 minutes.
Sheep Nos.:		575	4 hours 30 minutes.	647	2 hours 2 minutes.
583	22 hours 7 minutes.	609	8 hours 40 minutes.		
590	3 hours.	583	2 hrs.		

The time elapsing varied between 50 minutes in the case of Sheep 628, and 22 hours and 7 minutes in the case of the first experiment with Sheep 583. In this case, however, it is probable that the time is very much too long, because no observation was made upon the animal from 4.47 p. m., June 21, to 9.22 a. m., June 22. It is to be presumed that the animal was sick during the night. Excluding this animal, the maximum time elapsing was 8 hours and 40 minutes, in the second poisoning case of Sheep 609. Excluding, too, the case of Sheep 583, the average of all these sheep cases was 2 hours and 58 minutes.

TOXIC AND LETHAL DOSAGE.

It is evident that a number of factors may affect the toxic dosage of any plant. Most prominent among these factors are the method of feeding, the age of the plant, the part of the plant used, and the kind of animal used for experimental purposes. Any figures in regard to dosage may have a considerable margin of error, as very few animals are subject to experiment under exactly the same conditions.

Effect of method of feeding.—Two methods of feeding were used with the experimental animals, forced feeding with the balling gun and feeding the plant mixed with hay.

Only two sheep, Nos. 564 and 578, were made sick by feeding the plant with hay. They were fed leaves, stems, and buds. The smallest effective dose of leaves, stems, and buds when fed by the balling gun, is 1.096 pounds. The smallest dose of the two animals fed in hay was 0.284 pound in the case of Sheep 564. Apparently the animals fed with hay were made sick on a smaller dosage. There is some doubt, however, in regard to the accuracy of the dosage figures in the case of Sheep 564. Five head of cattle were given the plant in hay, with a minimum dosage of 0.264 pound.

Influence of age of the plant.—It was at first thought that the collections early in the season were somewhat more toxic than those obtained later. A careful examination of the cases, however, does not bear this out. So far as present evidence is concerned, then, the plant is nearly equally toxic at all seasons.

Comparative toxicity of parts of the plant.—An examination of the dosage (Table 1) shows very clearly the extreme toxicity of the seed. The fruit heads stand next, while there is no evidence to show any material difference in the toxicity of the other parts of the plant. It should be stated, however, that of course the weight of seed is of dry material, while the weights of the other parts of the plant are of green material. It would follow, then, that the difference between the toxicity of the seed and the other parts of the plant is not so great as the table indicates.

Effect on different animals.—Only two classes of animals, cattle and sheep, were used in these experiments, and most of the sheep were fed by the balling gun. Comparing Cattle 861 and 863, which received leaves, stems, and young fruit, with Sheep 583, 590, 599, 602, and 605, which were made sick on similar material, it appears that the plant is about twice as toxic for cattle as for sheep. This, if true, is an interesting fact, but probably not of any especial practical importance, as there is no reason to think that cattle on the range eat much of this plant.

As a general statement regarding the toxicity of *Z. paniculatus* it would probably be safe to say that, excluding the fruit and the seed, the toxic dose of the plant is between 1 and 2 pounds per hundredweight of animal.

Fleming [3] gives as minimum toxic doses for yearling calves three-eighths of a pound, and with regard to sheep states that less than one-fourth of a pound rarely produces poisoning symptoms, and in a

[3] Annual Report of the Board of Control for the fiscal year ending June 30, 1919. Agricultural Experiment Station, University of Nevada, Department of Range Management. 1920, pp. 42–43.

few cases over 1 pound has been fed with negative results. Sheep most frequently have been made sick with amounts in excess of 1 pound, while most of the deaths have resulted from $1\frac{3}{4}$ to 4 pound feedings. Fleming does not give the weights of the animals. If it is assumed, however, that his sheep weighed 100 pounds each, his figures for sheep would not differ widely from those obtained by us. If his yearling calves were well grown, his figures for cattle would be much smaller than those in this paper. In any case, he seems to have found the plant much more toxic for cattle than for sheep, thus far confirming the apparent result of the work reported here.

Toxic dose of Z. paniculatus compared with Z. gramineus.—It is difficult to make anything like an exact comparison of the present results with those given in Bulletin 125 for *Z. gramineus*, because the experiments on *Z. gramineus* were not very carefully checked up with regard to loss of moisture. The *Z. gramineus*, however, was ordinarily used fresh, so that this difference is not so great as it otherwise would be. In the case of *Z. paniculatus*, as quoted in the bulletin, the material used was several days old, and without doubt the dosage would be multiplied by four to bring the figures to green weight. As compared with *Z. gramineus*, the seeds and fruit heads of *Z. paniculatus* are fully as toxic, but the other parts of the plant are much less toxic. The work with *Z. gramineus* showed that in a general way the toxic dose was about 0.5 pound, while the work with *Z. paniculatus*, as stated above, indicates that in a general way the toxic dose is between 1 and 2 pounds, or it may be said that *Z. gramineus* is approximately three times as poisonous as *Z. paniculatus*.

Lethal dosage.—Only one death occurred during the experimental work with *Z. paniculatus*, that of Sheep 644, on 2.5 pounds, and this animal suffered from pneumonia. That it will and does kill under range conditions, however, is abundantly proved by many well-authenticated cases.

LOSSES FROM Z. PANICULATUS.

The stockmen, of course, make no distinction between the species of death camas. Moreover, the systematic botanists are by no means agreed as to the determination of species or the names which should be applied to them. This confusion makes it difficult to state definitely whether reported losses from death camas should be ascribed to one species rather than another. From the distribution of *Z. paniculatus*, as given on page 3, it may be assumed that most of the death-camas losses in Utah, Nevada, Idaho, and eastern Oregon are caused by this species. These losses have been very heavy.

ZYGADENUS ELEGANS.

DESCRIPTION AND DISTRIBUTION OF THE PLANT.[4]

Zygadenus elegans, shown in Plate III, is an erect perennial herb with leafy stems arising from coated bulbs. Often numerous bulbs are together, forming clumps; three are so grouped in the picture. The linear grasslike leaves are one-sixth to one-half inch broad, 4 to 12 inches long, and are much whitened, particularly when young; the lower ones are sheathing at base, the upper without sheaths.

The flowers are in racemes which are simple or somewhat branched below, and often few-flowered. Under the flowers are ovate-lanceolate purplish bracts. The greenish straw-colored or whitish flower segments are one-fourth to five-twelfths of an inch in length and adhere to the base of the ovary. The glands of the upper flower segments are obcordate. The ovary is ovate in form and the stamens are included.

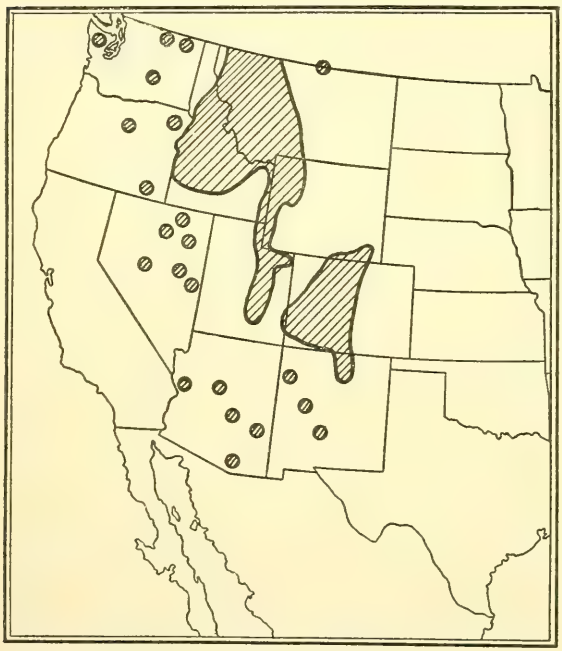

FIG. 5.—Distribution of *Zygadenus elegans* in the western part of the United States.

In the western part of the United States (figure 5) this plant ranges from the Olympic Mountains, Washington, east to central Montana and southward through central Oregon and central Nevada to southern Arizona and east to central New Mexico. In this region it is a high-mountain plant ranging from 2,500 to 13,000 feet. The natural habitat of *Z. elegans* is moist meadows and springy places from the yellow-pine to the arctic-alpine zones. Near the Salina Experiment Station the plant buds early in July, is in flower from the middle of July, and seeds in August and September.

Distinction between Z. paniculatus and Z. elegans.—The technical description already given will serve to distinguish clearly the two species treated of in this bulletin. The stockman, however, using the country within the range of these plants, can readily separate

[4] The description of *Z. elegans* and its distribution was prepared by W. W. Eggleston, of the Bureau of Plant Industry, U. S. Department of Agriculture.

ZYGADENUS ELEGANS. THREE PLANTS GROWING TOGETHER. THE DRIED STEM OF THE PLANT OF THE PRECEDING YEAR IS ALSO SHOWN.

them by their general appearance and habits. *Z. paniculatus* has thick, spreading leaves, while *Z. elegans* has thin, grasslike leaves. *Z. paniculatus* grows in dry, somewhat exposed places at elevations not exceeding about 8,500 feet. *Z. elegans* grows in damp places in meadows, or along small streams, sometimes actually in the water, at others on shady, damp hillsides, and generally in the western mountains at elevations above 8,000 feet. So far as the western ranges are concerned, *Z. elegans* might be called the mountain camas.

EXPERIMENTAL FEEDING.

Experimental feedings of *Z. elegans* to sheep were made in the summers of 1915, 1917, 1918, 1920, and 1921. No definite results were obtained in 1915 and 1918. It appeared later that the dosage in most of these cases was too small to produce intoxication. Inasmuch as during these two years exact data regarding loss of moisture in the plants used were not recorded, the results can not be compared with those of 1917, 1920, and 1921, and it seemed best not to include these experiments in the summarized statement of Table 6. In 1917 there were 11 experimental feedings of sheep, 8 animals being more or less affected. In 1920 there were 21 experimental feedings, resulting in 9 cases of poisoning and 1 death. In 1921 there were 8 feedings, with 2 cases of poisoning. Table 6 gives a summarized statement of the cases of these three years.

TABLE 6.—*Summary of feeding experiments with Zygadenus elegans at Salina Experiment Station, 1917, 1920, and 1921.*

Animal.		Date of feeding.	Method of feeding.	Part of plant fed.	Weight of plant estimated as green plant per 100 pounds of animal.	Result.	Date and place of plant collection.	Remarks.
Designation.	Weight.							
Sheep Nos.:	*Pounds.*	1917.			*Pounds.*		1917.	
431	79	July 14	Balling gun	Leaves, stems, and flowers	2.791	Not sick	Nioche, July 13	
450	80.5	July 15	do	Leaves, stems, flowers, and bulbs	3.494	Sick	Manti Forest, July 13	In 2 forced feedings.
441	97	July 16	do	do	2.273	do	do	
445	96 to 90	do	do	Leaves, stems, and flowers	3.72	Symptoms	Yogo Creek, July 15	
444	92 to 85	July 17	do	do	4.792	do	Yogo Creek, July 16	
445	90 to 89	July 20	do	Leaves, stems, flowers, and bulbs	3.674	Sick	Between Yogo and Nioche, July 19.	
456	100 to 83	July 24	do	Bulbs	2.205	Not sick	Between Yogo and Nioche, July 23.	
449	86.5 to 81.5.	July 25	do	Leaves, stems, and flowers	5.097	Symptoms	do	
455	98 to 89.5	Aug. 1	do	do	5.625	do	Between Yogo and Nioche, July 31.	
455	98 to 89.5	Aug. 2	do	do	2.475	do	do	
453	98.5 to 97.5.	Aug. 2 to 8	Fed	do	16.527	Not sick	Between Yogo and Nioche, July 30.	
		1920.					1920.	
567	91.75	July 9	Balling gun	Leaves, stems, and buds	1.984	do	Blackham's Corral, July 8.	In 1 feeding.
571	75.5	July 10	do	do	2.425	Sickness salivation.	do	Do.
574	80	July 12	do	do	1.970	Symptoms	do	In 1 feeding, partially dried plant used.
577	88	July 14	do	do	2.866	Not sick	Blackham's Corral, July 13.	In 1 feeding.
580	73.25	July 15	do	do	4.555	Symptoms	do	Vomited.
585	75.5	July 16	do	do	3.832	do	do	In 4 feedings. Nausea.
588	101.25	July 19	do	Leaves, stems, and flowers	2.939	Sick	Salina Experiment Station, cattle pasture, July 19.	In 9 feedings in 3 hours; plants in full bloom.
599	96.5	July 23	do	do	6.153	Death	do	In 6 feedings; plants in full bloom.
604	130	July 29	do	do	3.431	Slight sickness.	Cattle pasture, July 26	In 5 feedings.
564	100	Aug. 6	do	Leaves and stems	3.748	do	Cattle pasture, Aug. 5	Flowers and fruits, heads removed; in 4 feedings.
588	105	Aug. 31	do	Fruit heads	0.661	Not sick	Sheep Hollow, Aug. 30.	Plant nearly ripe.
591	123	Sept. 2	do	do	1.009	do	Sheep Hollow, Aug. 31.	In one feeding.

601	105	Sept. 7	do	Pods and seed	0.840	do	Sheep Hollow, Sept. 4.	Pods fully developed. The feeding included the pods and seed from the equivalent of 500 grams of fruit heads per 100 pounds of animal.
594	114	Sept. 9	do	Fruit heads	2.437	do	Sheep Hollow, Aug. 25.	One feeding, pods three-fourths developed; fed dry.
600	94.5	Sept. 10	do	do	2.205	do	Sheep Hollow, Sept. 9.	In 2 feedings.
606	109	Sept. 13	do	Ripe seed (dry weight)	0.187	do	Sheep Hollow, Aug. 30.	In 1 feeding; fed dry; weight given is dry weight.
578	105	Sept. 15	do	do	0.331	do	do	Do.
564	108.5	Sept. 18	do	do	0.386	do	do	Do.
569	113.5	do	do	Leaves, stems, and a few pods	3.668	Symptoms	do	In 2 feedings. Seed had been removed.
568	94	Sept. 21	do	Ripe seed (dry weight)	0.496	Not sick	do	In 1 feeding; quantity fed given as dry weight.
580	73.75	do	do	Leaves, stems, and a few pods	4.409	Sick	do	In 2 feedings; seed had been removed.
		1921.						
622	76.5	June 20	do	Seed	0.606	Not sick	Sheep Hollow, Sept. 4, 1920.	Dry weight.
625	73	June 22	do	Leaves and very few stems and buds.	2.205	Sick	Sheep Hollow, June 21, 1921.	
629	106.5	June 23	do	do	1.984	Not sick	do	
628	95.25	June 24	do	Seed	0.772	do	Sheep Hollow, Aug. 3, 1920.	Do.
630	106.5	June 27	do	do	0.807	do	do	Do.
638	70	June 29	do	Bulbs	2.205	do	Sheep Hollow, June 28, 1921.	
633	92	Aug. 31	do	do	2.8	do	Sheep Hollow, Aug. 29, 1921.	
624	92.5	Sept. 6	do	do	3.	Symptoms	Sheep Hollow, Sept. 5, 1921.	

TYPICAL CASE OF SHEEP 588.

In most of the cases the symptoms were neither very acute nor very prolonged. Sheep 588 may be considered fairly typical of one of the more pronounced cases. This sheep was a yearling wether weighing 101.25 pounds at the time of the experiment. It was taken into the corrals for observation on the morning of July 17, 1920. The experimental feeding was commenced July 19, 1920. On account of the large quantity necessary to produce toxic effect, the plant was administered in several doses. At 10.57 a. m. 200 grams of stems, leaves, and flowers of the plant were given. The sheep was somewhat salivated as the result of this feeding, but no further symptoms developed during the administration of the plant. Other feedings were made at 11.15 a. m., 11.37 a. m., 11.51 a. m., 11.57 a. m., 12.06 p. m., 12.22. p m., 1.10 p. m., and 1.20 p. m. At these feedings quantities varying from 100 to 200 grams were given. The feeding in each case occupied about five minutes. All told, the animal received an equivalent of 2.939 pounds of green plants to 100 pounds of animal.

No symptoms were noted until 4.24 p. m. At that time the sheep was regurgitating and frothing at the mouth. The temperature was 102.8° F., pulse 100, respiration 72. At 5.30 p. m. the animal was still badly salivated, and was standing with the hind legs braced back and head held rather high. The respiration was fast and deep. At 5.55 p. m. the animal showed unsteadiness when attempting to walk. There was at this time distinct hyperesthesia; it was startled by sudden noises or by being touched. The condition remained the same during the evening. Observations continued until 10.30 p. m. The salivation continued and the animal was unsteady on its feet, and occasionally, when startled, would fall down but was able to get upon its feet again. At 9.45 p. m. and 10.30 p. m. it was found lying down but got up readily, although its gait when walking was very unsteady.

On July 20, at 7.10 a. m., when observed it was still salivated, was quiet and depressed, but much stronger than the night before. During the day the condition of the animal improved gradually and on the morning of July 21 it was turned into the pasture, as it seemed to have recovered completely.

DISCUSSION AND RESULTS.

SYMPTOMS.

Salivation.—Salivation occurred in all but 2 of the cases. There was evidence of nausea in 6 cases. In some of these cases this was shown by more or less regurgitation. Actual vomiting occurred in 5 animals.

Weakness.—Pronounced weakness was noted in 14 of the animals.

Temperature.—There was no evidence of any effect on temperature. In this connection perhaps it should be noted that none of the animals, with the exception of Sheep 599, were very sick, and few temperature observations were made on this animal.

Pulse.—No effect on the pulse was noted.

Respiration.—Sheep 599, which was very sick and died, had an irregular respiration that at times was labored. Irregular respiration was noted in Sheep 625. In other cases labored respiration was noted.

Trembling and heightened reflexes.—It is interesting to note that 2 animals, Sheep 588 and 599, exhibited hyperesthesia, and one, Sheep 599, showed muscular trembling. These symptoms were noted quite generally in the *Z. gramineus* cases seen in Montana, but were not seen in the *Z. paniculatus* animals.

In general, the symptoms closely resembled those seen in the effects of the other species of Zygadenus, differing only in degree.

DURATION OF SYMPTOMS.

Table 7 shows the time during which the symptoms continued. As in the similar table for *Z. paniculatus*, the time was computed from the first noted symptom to the last observation.

TABLE 7.—*Duration of symptoms.*

Animal.	Duration of illness.	Animal.	Duration of illness.
Sheep Nos.:		Sheep Nos.—Contd.	
450	6 hours.	580	5 hours.
441	1 hour.	585	1 observation.
445	do.	588	15 hours.
444	5½ hours.	599	6½ hours to death.
445	10 minutes.	604	20 hours.
449	2½ hours.	564	3 hours.
455	1 observation.	569	Do.
455	do.	580	4½ hours.
571	1 hour.	625	20 hours, 6 minutes.
574	1 observation.	624	11 hours, 19 minutes.

The average time of all the cases was 5 hours and 17 minutes. Sheep 599, which died, was sick 6½ hours. The shortest periods of illness were those in which a single observation was made; the longest was 20 hours and 6 minutes.

As compared with *Z. paniculatus* the sickness was of shorter duration.

TIME REQUIRED TO PRODUCE SYMPTOMS.

Table 8 states the time elapsing between the feeding of the plant and the development of symptoms. In some of these cases repeated feedings were made, so that the administration of the plant extended over a considerable period of time. In Sheep 588, for example, the plant was given in 9 feedings involving a period of 3 hours. The

times given in the table are computed from the time when the feedings were finished.

TABLE 8.—*Time elapsed from feeding to development of symptoms.*

Animal.	Time.	Animal.	Time.
Sheep Nos.:		Sheep Nos.—Contd.	
450	Immediately.	580	Immediately.
441	5 minutes.	585	6 hours.
445	12 minutes.	588	3 hours.
444	28 minutes.	599	8 minutes.
445	Immediately.	604	2 hours, 24 minutes.
449	14 hours, 55 minutes.	564	2 hours, 36 minutes.
455	Immediately.	569	Immediately.
455	do.	580	5 hours.
571	5 hours.	625	10 minutes.
574	7 hours.	624	7 hours, 37 minutes.

In some of the animals the symptoms followed immediately after the feeding. The longest time before symptoms was 14 hours and 55 minutes in the case of Sheep 449. This probably is longer than the actual time, for the symptoms were first noted in the morning and it is probable that the animal had been sick during the night. Excluding Sheep 449 the average time elapsing between the feeding and the development of symptoms was 2 hours and 5 minutes. On the average the symptoms appeared somewhat more quickly than was the case with *Z. paniculatus*.

RESULT OF AUTOPSYS.

Opportunity was found for only one autopsy, that on Sheep 599. In this animal the left ventricle was contracted and the right expanded. The left lung was highly congested, and the right lung congested to the point of hepatization. The extreme condition of the right lung was probably due to hypostasis. No other abnormal conditions were noticed.

TOXIC AND LETHAL DOSAGE.

Table 6 shows the dosage of the animals poisoned in 1917, 1920, and 1921.

To determine the probable toxic dosage of the plant it is necessary, of course, to consider only the minimum quantities required to produce intoxication or death.

It should be noted in connection with this table that although both seeds and fruit heads were used, no results were obtained from the dosage used from these parts of the plant. Sheep 630 received 0.807 pound of seed with no effect, and Sheep 594 received 2.437 pounds of fruit heads with no effect.

So far as Table 6 is concerned, it appears that in general terms the toxic dose of *Z. elegans* varies from 2 to 4 pounds per 100 pounds of animal.

Lethal dose.—Only one animal, Sheep 599, was killed by *Z. elegans*. The quantity used in this case was 6.153 pounds of leaves, stems, and

flowers. Sheep 455 received 5.625 pounds of leaves, stems, and flowers with the result that only symptoms were produced. It seems fair to presume that the lethal dose is about 6 pounds per 100 pounds of animal.

Comparative toxicity of different parts of the plant.—The dosages shown in the table do not give any clear indication regarding the relative toxicity of different parts of the plant. It appears probable, however, that the stems are less toxic than the other parts of the plant, that the bulbs are certainly no more toxic than the other parts, and that the plant is possibly somewhat more poisonous in the bud stage than later in the season.

Probably no cumulative effect.—In 1915 Sheep 334 received for 13 days an average daily dose of 1 pound of leaves, stems, buds, and flowers. The feeding was commenced July 16 and terminated on July 29, when the animal died from choking. The animal was salivated July 17, 19, and 20 and seemed somewhat depressed. These symptoms, however, did not increase in the succeeding days. In fact, after July 20 no symptoms were noticed except slight depression.

In 1919 Sheep 453 received for seven days an average daily dose of 2.361 pounds of leaves, stems, and flowers with no effect. In this same year Sheep 455 received 5.625 pounds of leaves, stems, and flowers on one day and on the succeeding day 2.475 pounds. The sheep exhibited symptoms on both days, but was not seriously affected, although the dose of the first day was very large, and that of the second greater than the minimum toxic dose. These experiments were not numerous enough to form the basis for a dogmatic statement, but they are nevertheless significant, and indicate the probability that there is little, if any, cumulative effect in poisoning by *Z. elegans.*

Comparison of dosage with that of Z. elegans in 1913.—In Bulletin 125 was reported the poisoning of two experimental sheep at Greycliff, Mont., by *Z. elegans* obtained from the Beartooth National Forest. It was stated that Sheep 199 showed symptoms from 0.44 pound of leaves, stems, flowers and some fruit, and that Sheep 185 showed slight sickness from 0.66 pound of leaves, stems, flowers and some fruit. Apparently this is a very much smaller dosage than that in the present work at the Salina Experiment Station. In the experiments with this plant at Greycliff, Mont., however, no account was made of the loss of weight by drying. In all the later work careful drying experiments have been made and it has been found that the plants suffer a surprising loss of moisture in a short time. The Beartooth National Forest material was collected July 20, 1913, and used July 28. We now know that it must have lost at least 75 per cent of its weight in that time, so that if we estimate the dosage in

green weight the figures for the dosage of Sheep 199 and 185 should be multiplied by four. This makes the dosage compare fairly well with the 1920 experiments.

COMPARATIVE TOXICITY OF Z. GRAMINEUS Z. PANICULATUS, AND Z. ELEGANS.

From the somewhat insufficient data of the experimental work there have been tabulated the smallest effective doses in sheep of the three species of Zygadenus which have been examined. All these cases were of forced feedings with the exception of the feeding of seed of *Z. gramineus*.

TABLE 11.—*Comparative toxicity of Z. gramineus, Z. paniculatus, and Z. elegans; minimum effective dosage.*

Part of plant.	Z. gramineus.	Z. paniculatus.	Z. elegans.
	Pound.	*Pounds.*	*Pounds.*
Leaves, stems, and young fruit	0.757	1.505	
Leaves and stems	.33	1.984	3.748
Fruit heads	.141	.62	
Seed	[1] .092	.07	
Leaves, stems, and buds	.495	1.096	1.97
Leaves, stems, and flowers			2.939
Leaves, stems, flowers, and buds	.495		
Leaves, stems, flowers, and bulbs			2.373

[1] Fed.

Table 11 shows those cases which received similar material. It is impossible, of course, to determine from a table of this character the relative toxicity of the plants with any degree of exactness. It appears, however, that, put in a general way, *Z. gramineus* is three times as toxic as *Z. paniculatus*, and seven times as toxic as *Z. elegans*. It is interesting to note that, so far as the experiments are concerned, the toxicity of the seed of *Z. gramineus* and *Z. paniculatus* is practically the same.

COMPARATIVE TOXICITY OF FRUIT AND SEEDS OF Z. PANICULATUS AND Z. ELEGANS.

Ripe fruit heads of both *Z. paniculatus* and *Z. elegans* were collected and the seed separated from the pods and weighed. In both species it was found that very close to one-half of the dry weight was seed. In one collection of nearly ripe *Z. elegans* the fruit heads were weighed separately from the rest of the plant and found to be 23.4 per cent of the entire plant exclusive of the bulbs and roots. From this it appears that in *Z. elegans* close to 11.7 per cent of the weight of mature air-dried plant is seed.

The comparative toxicity of fruit heads and seed of *Z. paniculatus* shows that most of the toxic element of the fruit heads is in the seed. Sheep 569 was made very sick on 0.661 pound of green fruit heads, a sample of which lost 77 per cent in drying. This, then, was equivalent to 0.152 pound of dry material. Sheep 609 was made sick on 0.124 pound of dry fruit heads. Sheep 583 was made very sick on

0.07 pound of seeds, or almost exactly one-half the dose of the whole fruit head.

Drying experiments make it possible to figure the doses of various parts of the plant given in terms of dry material. Inasmuch as the seeds fed were dry, this is desirable in making comparisons of relative toxicity of seeds and other portions of the plant. When this is done it appears that with *Z. paniculatus* the seeds are twice as toxic as the fruit heads and four times as toxic as leaves, stems, and flowers, while the fruit heads are about twice as toxic as leaves, stems, and flowers. That this ratio does not hold with *Z. elegans* is shown by the feeding of 0.463 pound of dry fruit heads and 0.807 pound of seed without effect when 0.623 pound was found to be a toxic dose of dry leaves, stems, and flowers. In other words, fruit heads or seeds of *Z. elegans* are little if any more toxic than leaves, stems, and flowers.

Z. ELEGANS NOT ESPECIALLY DANGEROUS FOR SHEEP.

If sheep were to graze on *Z. elegans* they would rarely get the bulbs, although these can sometimes be pulled up, as the plant grows in wet ground and the bulbs are not far from the surface. The feeding would be largely on the aerial parts of the plant, and of these it is thought that the fruit and seeds would seldom be eaten, as they are dry and unattractive. Of the parts of the plant likely to be eaten it would take from 1.5 pounds to between 3 and 4 pounds per 100 pounds of animal to poison an animal and 6 pounds to produce a fatal effect. It follows that poisoning from *Z. elegans* is not likely to occur, as sheep would seldom eat so large a quantity. Moreover, *Z. elegans* grows in localities where there is ordinarily an abundance of vegetation, so that animals would not be forced to eat it because of a lack of other forage. While both *Z. gramineus* and *Z. paniculatus* may and do cause losses, *Z. elegans* can be hardly be reckoned as an important poisonous plant; in fact, it is doubtful whether it causes any losses on the range.

SUMMARY.

1. In preceding investigations of the species of Zygadenus, known popularly under the collective name of "death camas," little attention has been given to the comparative toxicity of the various species.

2. Detailed studies of *Z. paniculatus* and *Z. elegans*, compared with preceding work with *Z. gramineus*, have shown a marked difference in toxicity.

3. *Z. paniculatus* is found to be about one-third as toxic as *Z. gramineus*, and *Z. elegans* about one-seventh.

4. While *Z. paniculatus* is not so toxic as *Z. gramineus*, it is a distinctly dangerous plant, and is the cause of heavy losses of livestock. *Z. elegans*, however, while it may poison livestock, probably does little or no damage under practical range conditions.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 1013

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Bureau of Markets and Crop Estimates
H. C. TAYLOR, Chief

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THE INFLUENCE OF RELATIVE HUMIDITY AND MOISTURE CONTENT OF WHEAT ON MILLING YIELDS AND MOISTURE CONTENT OF FLOUR.

By J. H. SHOLLENBERGER, *Grain Supervisor, in Charge Milling Investigations.*

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INTRODUCTION.

It is common knowledge among millers that the total weight of the products obtained in milling almost invariably differs from the weight of the wheat used. This difference in weight is due largely to changes occurring in the moisture content of the wheat during its preparation for grinding and throughout the process of milling; therefore, any factor influencing the amount of moisture which becomes added to wheat or evaporated therefrom in its preparation for milling and during the different steps of milling influences to that extent the percentage yield of mill products.

The results of certain milling tests conducted in the experimental mill operated by the Federal Bureau of Markets and Crop Estimates at Washington, D. C., indicate the nature of some of these factors and the extent of their influence. Information was obtained on the following subjects: The influence of the relative humidity of the air within the mill and of the moisture content of hard wheats when

tempered to 15 per cent moisture on the invisible losses occurring during the milling process and on the total yield of mill products; also the influence of the temperature of the air within the mill upon the total yield of mill products.

HUMIDITY.

That the humidity of the atmosphere in the mill influences milling results is commonly known to millers. This influence, however, the miller is able to control to a certain extent by varying the tempering or conditioning process applied to the wheat and the manner of grinding and bolting, provided he can anticipate any change that is likely to take place in the humidity of the atmosphere. Advance information of the weather, however, can not always be depended upon; consequently, the miller can not always have his wheat conditioned and his mill adjusted properly for obtaining the highest degree of efficiency possible. Certain atmospheric conditions are generally recognized as being more conducive to good milling results than others; therefore, the installation of means for controlling the condition of the atmosphere within the mill would give to the miller a greater degree of control over the operation of his plant and thereby improve his results.

NORMAL MOISTURE CONTENT.

Evidence that an approximate parallelism exists between the moisture content of wheat and the relative humidity [1] of the atmosphere lies in the well-known fact that the normal moisture content of air-dry wheat is higher when stored in moist climates than when stored in dry climates. The term "normal" as used in this bulletin means that moisture content which is unaffected by continued exposure to the prevailing atmospheric conditions. In other words, it is that point at which equilibrium is established between the moisture content of the wheat and the humidity of the air. According to experiments by Stockham,[2] the moisture content normal for different wheats

[1] The amount of water vapor which can be mixed with a given quantity of air varies with its temperature; the higher the temperature, the greater the amount of water vapor it can hold. When air at a given temperature contains all the moisture possible for it to hold, it is said to be saturated. The percentage or ratio of the actual amount of moisture contained by a cubic unit of air to the amount which the same air would hold at the same temeprature if saturated is called the relative humidity. Relative humidity is usually stated in terms of percentage.

Since the capacity of the air for water vapor increases proportionately with temperature, every increase in temperature, assuming that the quantity of water vapor in the air remains the same, results in a lowering of the relative humidity, and every decrease in temperature results in a proportionate increase of relative humidity until the saturation point is reached, beyond which condensation occurs.

[2] Stockham, W. L., The Capacity of Wheat and Mill Products for Moisture. North Dakota Agr. Exp. Sta. Bul. No. 120, 1917.

and for their various mill products varies somewhat, even under the same atmospheric condition.

In milling, the practice of adding moisture to wheat in its preparation for grinding, which is usually referred to as tempering, may give to the wheat a moisture content above normal for the prevailing atmospheric conditions. Whenever this occurs and the wheat is exposed to the air, evaporation of this excess moisture begins. The quantity of moisture, however, actually evaporated from the wheat during milling is dependent upon a number of variables, including the quantity of moisture in excess of that normal for the prevailing atmospheric conditions, the distribution of the moisture, the length of time the material is exposed, the manner of exposure, the circulation of air, and the character of the material. Furthermore, because of the heat generated by the action of the various machines used in milling and other causes, the relative humidity of the air in different parts of the mill varies somewhat, affecting the rate and extent of the evaporation taking place at different steps in the milling process.

MATERIAL AND METHOD OF EXPERIMENTS.

The wheats used in the experiments conducted by the Bureau of Markets and Crop Estimates were milled on a special-type reduction machine, consisting of four pairs of 6-inch rolls, three corrugated and one smooth, together with a sifter and sieves appropriate for making the various separations of stock required. The quantity of wheat used in each test was 1,500 grams, or approximately 3 pounds. The wheats tested were hard wheats, representing various grades, qualities, and varieties, from various parts of the United States.

The system of milling used, although not the continuous automatic system employed in commercial mills, included all the various steps deemed necessary in modern milling practice. Figure 1 represents the flow sheet of the system used.

The time required to make each test averaged 1½ hours, which incidentally represents the period of time that each sample was exposed to the atmospheric conditions prevailing in the room in which the milling was performed. Before milling, each sample was cleaned, scoured, and tempered. No cleaning or scouring was performed after tempering. A determination of the moisture content of each cleaned and scoured sample was made previous to tempering. The tempering period ranged from 18 to 22 hours. The amount of temper water added depended upon the moisture content of the individual samples, enough being added to raise the moisture content to 15 per cent. During tempering, the samples were kept in air-tight cans which prevented any loss of moisture from the wheat from the beginning of the tempering period until the wheat started through

the first break rolls. In making the tests, care was taken to collect all the material ground. That some weight was lost through the

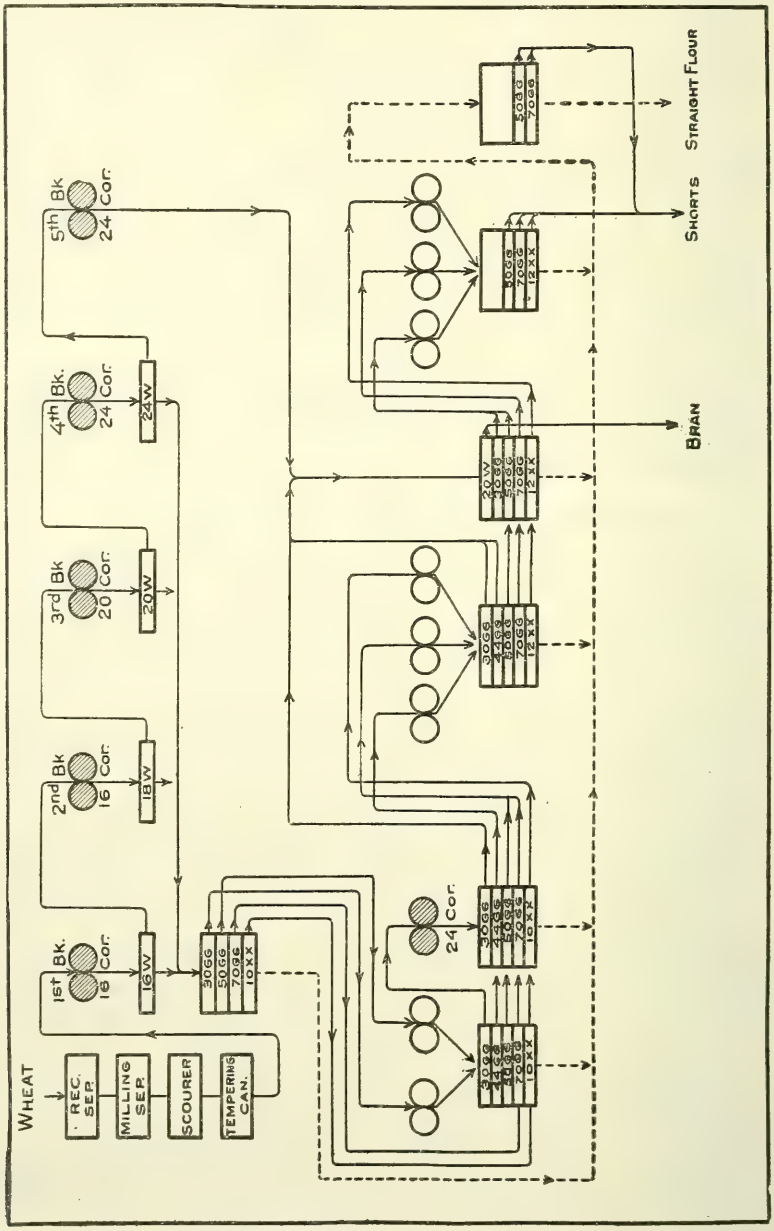

FIG. 1.—Flow sheet of experimental mill.

dusting out of fine particles into the air is quite probable, but the principal difference in weight between the wheat plus the temper water and the resultant mill products was due to evaporation during the process of milling.

The percentage yields indicated by the curves shown in the accompanying figures are based on the weight of the cleaned and scoured wheat samples before the addition of the temper water.

INFLUENCE OF RELATIVE HUMIDITY ON TOTAL YIELD OF MILL PRODUCTS AND INVISIBLE LOSS.

In figure 2 is shown the average total yield of mill products for various ranges of relative humidities. Because of the influence ex-

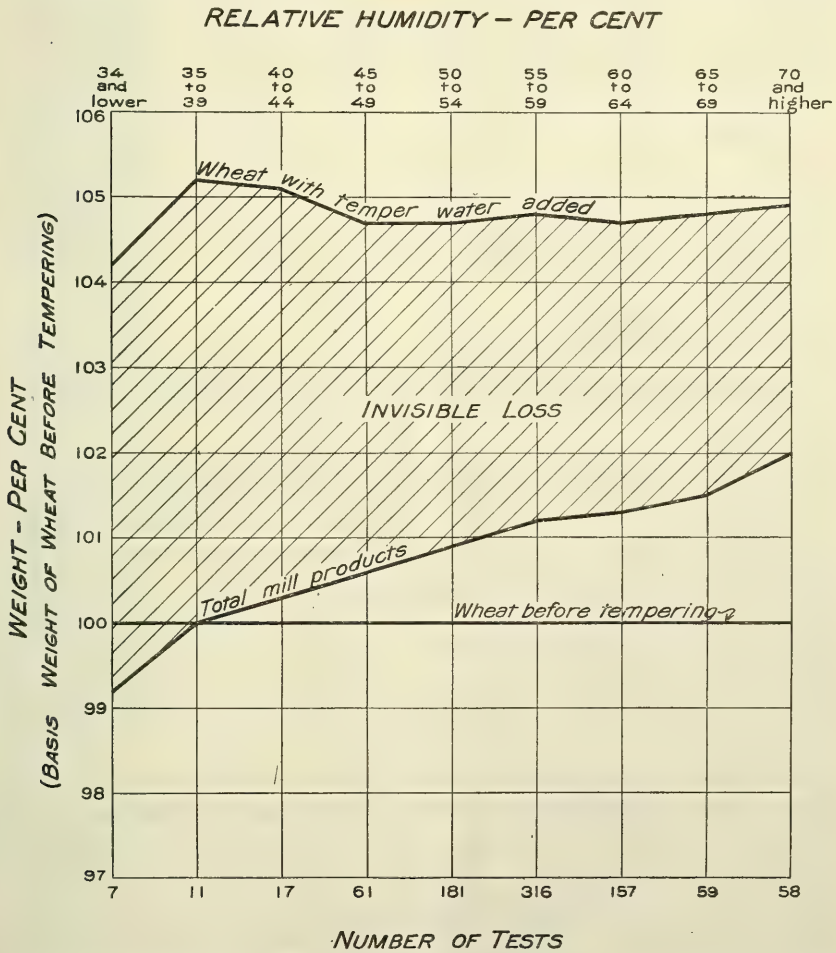

FIG. 2.—Showing that the invisible loss in milling decreases and the total weight of mill products increases with each increase in the relative humidity of the air within the mill.

erted on yields by the variation in the quantity of temper water which differences in the original moisture content of the various samples made it necessary to add in order to temper each of 15 per cent moisture, the curve shown represents the combined effect of relative humidity and moisture content of wheat on the total yield of mill

products. The shaded portion marked "invisible loss" is the difference in the weight of the wheat with the temper water added and the total weight of mill products obtained from milling. With each increase of relative humidity there is an appreciable decrease in the invisible loss occurring during milling and a proportionate increase in the total yield of mill products. For example, the average invisible loss resulting from milling 11 samples at relative humidities ranging from 25 to 29 per cent, inclusive, was 5.2 per cent, while in milling 59 samples at relative humidities ranging from 65 to 69 per cent, the average invisible loss amounted to only 3.3 per cent. This loss in weight is due principally to the evaporation of moisture contained in the wheat, and, except in the cases of low atmospheric humidity, amounted to less than the quantity of water added in tempering. In other words, the weight lost through the evaporation of moisture during milling was greater than the weight of the temper water added when the samples were milled at relative humidities lower than 35 to 39 per cent and less when milled at higher relative humidities.

COMPARISON OF THE INFLUENCE OF RELATIVE HUMIDITY AND OF MOISTURE CONTENT OF WHEAT ON MILLING YIELDS.

That both the relative humidity of the air and the moisture content of the untempered wheat have a considerable influence on the weight lost or gained during milling as compared with the weight of the wheat before tempering is quite evident from figure 3. In preparing this diagram the samples were grouped according to certain ranges in the percentages of moisture contained in the wheat samples before tempering, and a separate curve was made for each group. This scheme of diagramming makes it possible to show the relation of both relative humidity and moisture content to the total yield of mill products.

The curves show that the higher yields are associated with the higher relative humidities and with the wheats of lower moisture content. Each 10 per cent increase in relative humidity above 35 per cent shows an average increase of about one-half of 1 per cent in the total weight of the products obtained, and each decrease of 1 per cent in the moisture content of the wheat before tempering shows about six-tenths of 1 per cent increase in yield. Compared with the weight of the wheat before tempering, the samples containing from 9 to 9.9 per cent moisture showed a net gain in weight of total mill products for all relative humidities given, while the samples containing from 12 to 12.9 per cent moisture before tempering showed a net loss in weight of total mill products except for relative humidities higher than 60 to 69 per cent. The greatest average gain in weight

for any group was 3.8 per cent and the greatest average loss was 1.4 per cent.

In connection with the conclusions expressed in the preceding paragraph, it should be borne in mind that the increase in the total yield of mill products associated with the higher relative humidities was due, no doubt, to decreased evaporation during milling of the

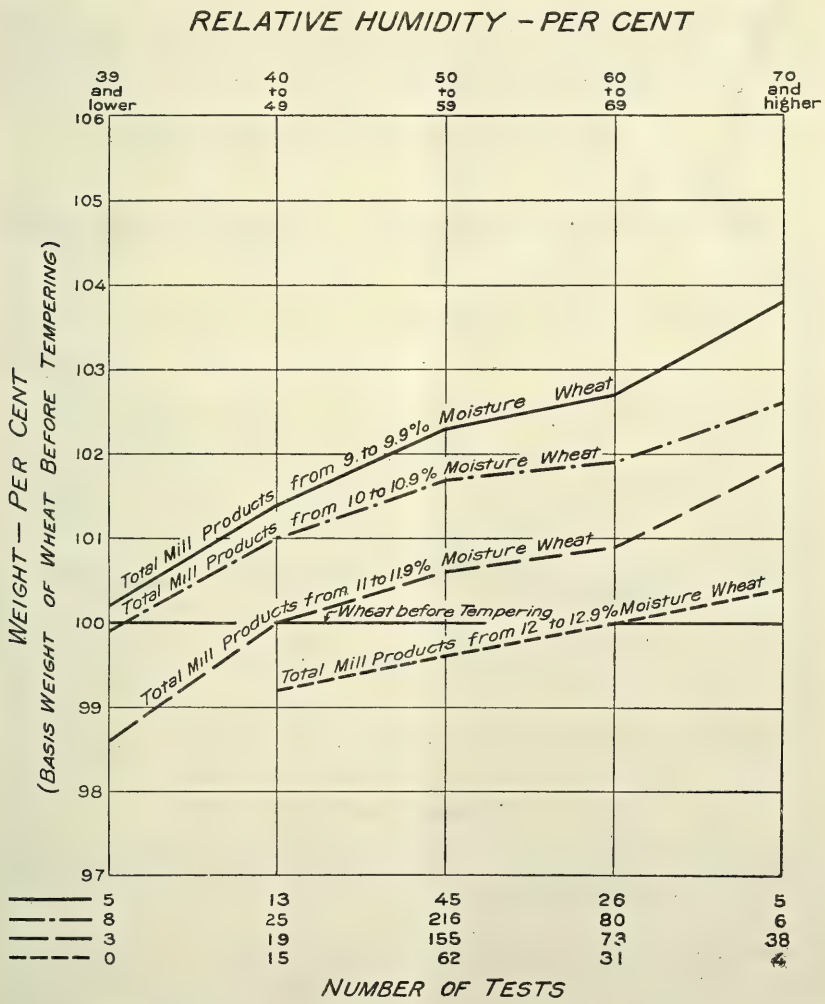

FIG. 3.—Relation of the relative humidity of the air within the mill and the moisture content of wheat to the total weight of mill products.

moisture contained in the wheat and in some cases to the absorption of moisture from the air by certain mill stocks, and, furthermore, that the increase in yields associated with the lower moisture content wheats was due to the greater amounts of water which it was necessary to add in tempering in order to bring the final moisture content of these wheats up to 15 per cent. The amounts of temper water

added to the samples, although not definitely stated in the diagrams, may be ascertained by subtracting from 15 per cent the percentage of moisture contained in the wheat before tempering.

INFLUENCE OF RELATIVE HUMIDITY ON MOISTURE CONTENT OF FLOUR.

Concerning the influence of atmospheric humidity on the moisture content of flour, Bailey[3] in his investigations on that subject concludes that "flour responds readily to changes in the humidity of

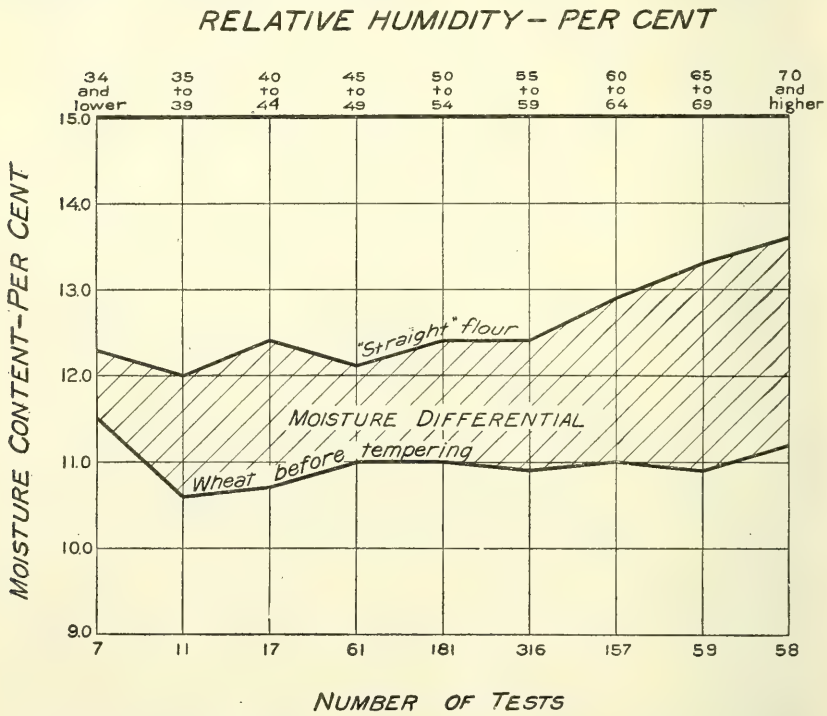

FIG. 4.—Showing that as the relative humidity of the atmosphere within the mill increases there is a corresponding increase in the moisture differential of the flour and of the wheat from which it is milled.

surrounding air, the rate at which equilibrium in moisture is approached depending apparently upon conditions of exposure."

An indication of the effect of relative humidity on the moisture content of the flour produced in connection with the experimental milling tests herein described is shown in figure 4. The results indicate a decided tendency for the moisture content of the flour product to be highest for the higher relative humidities. At relative humidities ranging from 35 to 39 per cent, the average

[3] Bailey, C. H. The Hygroscopic Moisture of Flour Exposed to Atmospheres of Different Relative Humidity, Journal of Industrial and Engineering Chemistry, vol. 12, No. 11, p. 1102. Nov., 1920.

moisture content of the flour produced was 12 per cent, and at 65 to 69 per cent relative humidity, the moisture content was 13.3 per cent, or an increase of 1.3 per cent moisture for a difference of 30 per cent in relative humidity.

It has been suggested that probably these are the normal moisture contents for flour at the respective relative humidities shown, but such a conclusion is not entirely justified, for the reason that in these tests no proof exists that the exposure of the flour to the air, which was limited to the length of time necessary for milling the sample, was sufficiently long to establish a state of equilibrium between the moisture content of the flour and that of the mill atmosphere. On the other hand, proof that at least some of these moisture contents are not normal is evidenced by the wide divergence from the results obtained by Bailey, to which reference has been previously made. For instance, he found that the hygroscopic moisture in flour in equilibrium with atmospheric humidity at 25° C. ranges from a little more than 5 per cent at 30 per cent relative humidity to 15 per cent at 60 per cent relative humidity.

COMPARISON OF THE INFLUENCE OF RELATIVE HUMIDITY AND OF MOISTURE CONTENT OF WHEAT ON THE MOISTURE CONTENT OF FLOUR.

Some indication of the comparative influence exerted on the moisture content of flour by each of the factors, atmospheric humidity and moisture content of the wheat before tempering, is given in figure 5. In this figure the results from samples which before tempering had moisture contents falling within various ranges are represented by separate curves. From this system of grouping it is possible to ascertain the particular influence exerted by each of these two factors. The proximity of the four curves to each other and their tendency to cross and recross each other indicate, for the method of tempering used in these experiments, no very pronounced relation between the moisture content of the flour and the moisture content of the wheat before tempering; or, in other words, no relation to the quantity of temper water added. On the other hand, a decided tendency is shown for the moisture content to increase as the relative humidity increases, a difference of 10 per cent in relative humidity making an average difference of approximately one-half of 1 per cent in the moisture content of the flour.

It would be interesting to know what influence, if any, variations in the final moisture content to which wheat may be tempered and the length of the tempering period would have on the resultant moisture content of the flour milled at different relative humidities. Since all samples were tempered to the same moisture content and for approximately the same length of time, it is impossible to draw any conclusions in regard to this influence from the results of these experiments.

Judging, however, from results obtained from other experiments, both the extent to which the moisture content of the wheat is raised in tempering and the length of time of tempering have an influence on the resultant moisture content of the flour product.

INFLUENCE OF ATMOSPHERIC TEMPERATURE ON THE TOTAL YIELD OF MILL PRODUCTS.

In addition to the influences of atmospheric humidity and moisture content of wheat, the possible influence of the temperature of the air within the mill on the total yield of mill products has also been

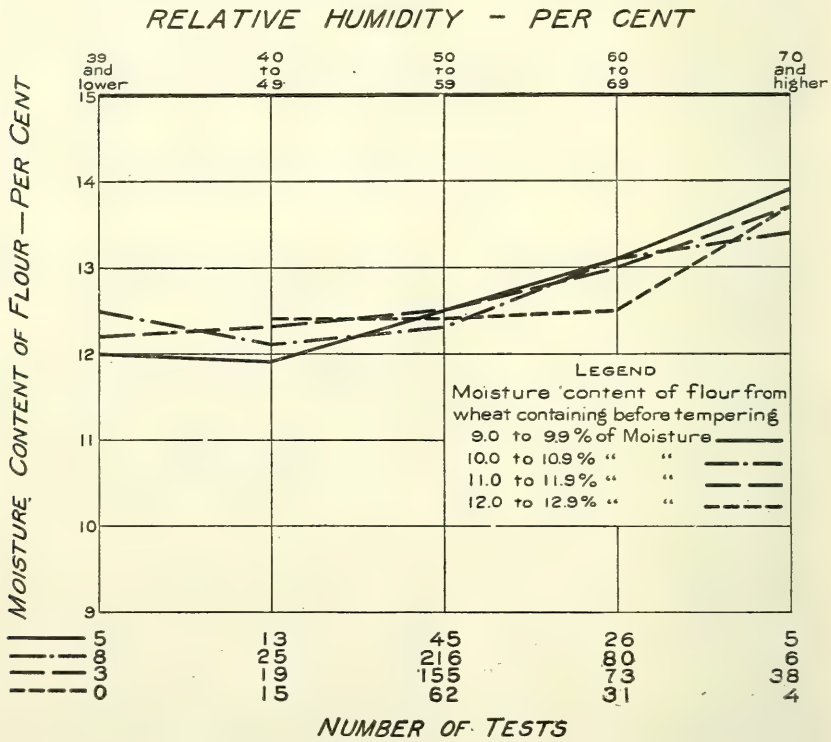

FIG. 5.—Relation of the relative humidity of the air within the mill and of the moisture content of wheat to the moisture content of the resultant flour.

given consideration and the results are represented by the curve shown in figure 6. In considering this factor, only the results obtained from those samples having approximately the same moisture content (10 to 10.9 per cent) before tempering, and which were milled at approximately the same relative humidity (50 to 59 per cent) were taken, in order that the results shown might be free from the influences of atmospheric humidity and moisture content. The curve in figure 6 shows the total yield of mill products obtained for various ranges of air temperature, and judging from the indefinite direction taken by this curve, no apparent relationship

between air temperature and yield of products can be established from the results of these investigations.

It is not contended that the experimental milling results given in this bulletin are entirely indicative of those occurring in commercial milling, but it is reasonable to believe that relative humidity and

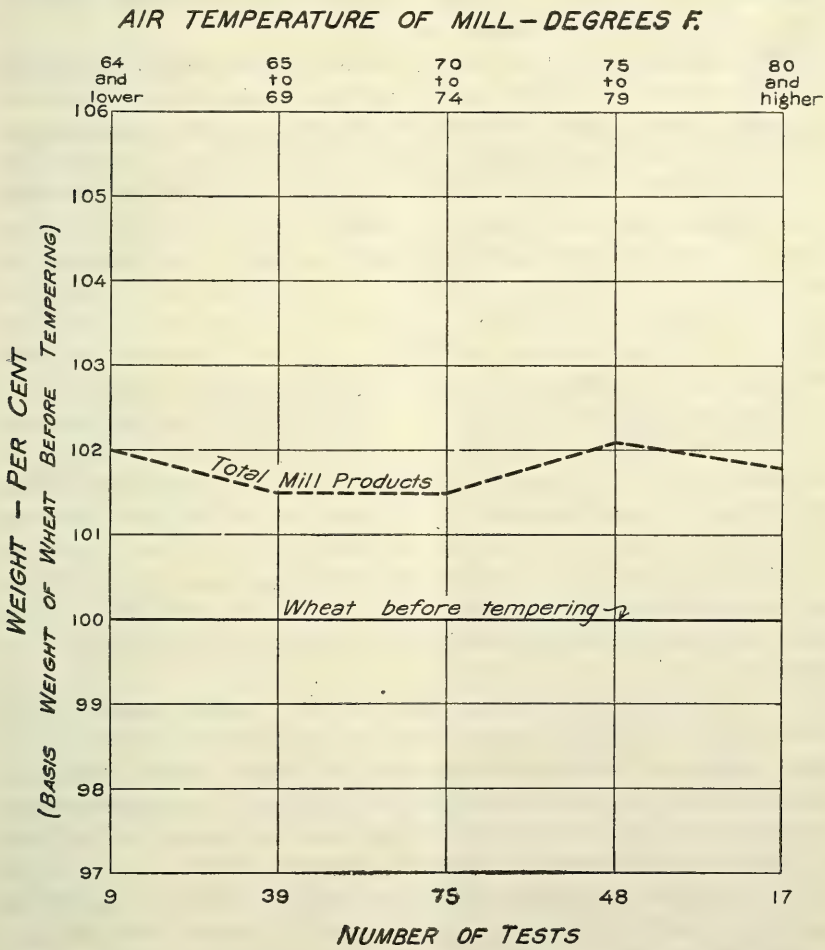

FIG. 6.—Relation of the temperature of the air within the mill to the total weight of mill products.

moisture content of wheat have a similar influence on the products of commercial milling plants, so that if any difference in influence does occur, it is only in degree and not in kind.

SUMMARY.

In brief, the conclusions that may be drawn from these experimental milling tests on hard wheats of various moisture contents, all

tempered to the same final moisture content of 15 per cent, are as follows:

With each increase of relative humidity or, in other words, with each increase in the extent to which the air within the mill became saturated with moisture, there was an appreciable decrease in the invisible loss occurring during milling and a proportionate increase in the total yield of mill products.

The higher total yields of mill products were associated with the higher relative humidities and with the wheats of lower moisture content. These higher yields in the former case were undoubtedly due to decreased evaporation during milling of the moisture contained in the wheat and probably to the absorption of some moisture from the atmosphere by some of the mill stocks; and, in the latter case of lower moisture content wheats, to the greater amounts of water which it was necessary to add in tempering these wheats in order to bring their moisture contents to the required percentage. Each 10 per cent increase in relative humidity above 35 per cent increased the total weight of the products obtained about one-half of 1 per cent, and each decrease of 1 per cent in the moisture content of the wheat before tempering caused about six-tenths of 1 per cent increase in yield. Compared with the weight of the wheat before tempering, the samples containing from 9 to 9.9 per cent moisture showed a net gain in weight of total mill products for all relative humidities given, while the samples containing from 12 to 12.9 per cent moisture before tempering showed a net loss in weight of total mill products except for relative humidities higher than 60 to 69 per cent.

No very pronounced relation between the moisture content of the flour and that of the wheat before tempering was shown, or in other words, no relation was shown of moisture content of flour to the quantity of temper water added to the wheat. On the other hand, a decided tendency was shown for the moisture content of the flour to increase as the relative humidity increased, a difference of 10 per cent in relative humidity, making an average difference of approximately one-half of 1 per cent in the moisture content of the flour.

No definite relation between air temperature and total yield of mill products was established.

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WM. A. TAYLOR, Chief

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EFFECT OF DATE OF SEEDING ON GERMINATION, GROWTH, AND DEVELOPMENT OF CORN.

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COMMONLY OBSERVED EFFECTS OF DATE OF SEEDING.

Corn growers in localities with a long season have observed that early and late seedings of the same variety of corn usually show wide differences in rate of growth, total growth, and number of days required to reach maturity. In general, corn which is seeded early requires a longer time to come up than that which is seeded later. The plants also grow more slowly, bear their ears lower, and do not attain so great a height. The number of ears to the plant, the size of the ears, and the number of suckers have not been found to be affected consistently by the time of seeding.

STATE EXPERIMENTS.

Numerous experiments on seeding at different dates have been conducted by the State agricultural experiment stations. The primary purpose of most of these experiments has been to determine the relative value of the different dates of seeding in influencing the crop yields. In the published results of some of the experiments the only data presented have been comparisons of yields from the different seedings. In others, additional data have been presented upon the height of stalks and the number of days from seeding to maturity.

In two series of experiments conducted by the Ohio Agricultural Experiment Station from 1883 to 1889, inclusive, and from 1908 to 1913, inclusive, the average yields from the different dates of seeding were as shown in Table 1. From 1885 to 1889 dates of ripening were recorded. The number of days to maturity is obtained from the recorded dates of seeding and ripening.

TABLE 1.—*Results of the date-of-seeding experiments with corn at the Ohio Agricultural Experiment Station in the 7-year period from 1883 to 1889, inclusive, and in the 6-year period from 1908 to 1913, inclusive.*

Series I.—1883 to 1889, inclusive.			Series II.—1908 to 1913, inclusive.	
Date of seeding.	Growth to maturity.	Yield per acre.	Date of seeding.	Yield per acre.
	Days.	*Bushels.*		*Bushels.*
Apr. 26 to 28	[a] 126	[a] 62.4	Apr. 24 to 29	63.9
May 2 to 6	[a] 121	[a] 61.1	May 4 to 10	68.5
May 13 to 16	[b] 118	[b] 70.9	May 14 to 17	67.4
May 22 to 26	[c] 119	[a] 62.4	May 25 to 28	54.9
June 2 to 5	[c] 115	[a] 53.0	June 2 to 6	44.3
June 14	[d] 116	[d] 51.5		

[a] Average of the records for five years.
[b] Average of the records for four years.
[c] Average of the records for three years.
[d] Average of the records for two years.

In experiments reported by the Indiana Agricultural Experiment Station for the years 1892, 1893, and 1894, the number of days from seeding to maturity decreased as the date of seeding was advanced at intervals of 10 days from May 6 to June 15. The averages of the results for the three years show that corn when sown on May 6 required 125 days from seeding to maturity; when sown on May 16, 120 days; and when sown May 24 to 26, 114 days. When sown June 4 and 5 it required 111 days, and when sown June 14 and 15 only 104 days. The average yields from experiments conducted during seven years (1888–1896)[1] were 46.7 bushels per acre[2] when sown May 1, 42 bushels when sown May 8 to 11, 39.5 bushels when sown May 15 and 16, 41.3 bushels when sown May 21 to 22, and 38.6 bushels when sown May 28 to 30.

The Illinois Agricultural Experiment Station during 1891, 1892, and 1893 conducted experiments in which seedings were made at weekly intervals from April 25 to June 3. The average results from the experiments during these three years showed that corn sown April 25 and 26 required 136 days from seeding to mature; May 2 to 7, 131 days; May 13 to 16, 131 days; May 20 to 27, 122 days; and June 1 to 3, 118 days. The maximum height of stalks was attained in the seedings made from May 10 to June 1. In experiments covering eight years (1888 to 1895) the maximum yields were obtained from the seedings of May 4 to 18. Seedings made in April and those made later than May 18 produced smaller average yields.

[1] No yields were reported for 1891 and 1895.

[2] Average of six years

The Kansas Agricultural Experiment Station in 1895 and again in 1896 made seven seedings of corn at intervals of one week from April 18 to May 30. The early seedings were slower in coming up than the later seedings. There were no consistent differences in yield from the seedings of April 18 to May 9, the April seedings yielding highest in some instances and the May seedings in others. The seedings of May 1 and 2, however, gave the highest yields of good ears. Seedings made later than May 9 gave greatly reduced yields.

The Oklahoma Agricultural Experiment Station in 1898 made seedings at intervals of one week from March 28 to April 25 and a last seeding on May 13. The March 28 seeding gave the greatest yield. The seeding of May 13 outyielded that of April 25; otherwise, the general tendency was for the yields to decrease as the seeding date was delayed. The plants from later seedings matured in less time than those from the early seedings; a difference of four weeks in the dates of seeding caused only eight days difference in the dates of maturity.

The Nevada Agricultural Experiment Station in 1894 made seven seedings of corn at intervals of 10 days from April 20 to June 20. The plants from the April 20 seeding required 142 days to mature; those of April 30 required 135 days and those of May 10 only 126 days. Data upon ripening were not recorded in connection with seedings made after May 10. The highest yield of ears was obtained from the April 20 seeding and the highest yield of stalks from the seeding of June 20. A difference of 10 days between the dates of seeding, April 20 and April 30, caused only three days' difference in the dates of ripening. A difference of 20 days between the dates of seeding, April 20 and May 10, caused but four days' difference in the dates of ripening.

Seedings of both dent and flint varieties were made by the South Dakota Agricultural Experiment Station at intervals of five days from May 1 to June 10 during 1888, 1889, and 1890. It is concluded from the experiments "that corn may be planted any time after May 1 without danger of the seed rotting, but no gain is made in yield or maturity by planting before conditions of soil and atmosphere are right. These conditions usually come between May 10 and 20. Plantings made during the first half of May showed no difference in yield or maturity."

In general, the experiments reviewed indicate that the best yields of grain may be expected from the early seedings and the most rapid development and the greatest growth from the later seedings. Neither the extremely early nor the very late seedings are desirable.

EXPERIMENTS AT THE ARLINGTON EXPERIMENTAL FARM.

The investigations reported in this bulletin were begun at the Arlington Experimental Farm, Rosslyn, Va., near Washington, D. C., in 1915, and have been continued since that date. They have been

directed more to a study of the effects upon growth and development than to determining the most desirable date of seeding from the standpoint of yield. Data have been obtained upon the rapidity of germination, the number of days from seeding to emergence, emergence to first silks, and emergence to ripening, the height of stalks, the number of ears per plant, the average weight of ears, the average yield per plant, and the number of suckers.

The varieties of corn used in the experiments cover a wide range in the length of the growing season required. No consistent effects have been observed upon the number of ears per plant, the size of ears, or the number of suckers. The data presented in the tables are limited to the characters that seem to have been consistently affected.

In 1915 24 varieties of corn were grown. The dates of seeding were April 20, May 20, June 21, and July 22. The varieties in each of the different seedings were sown in single rows 132 feet long and 3.3 feet apart on fairly uniform upland that had been in a mixed clover and grass sod the previous year. The rate of seeding was four kernels every 15 inches in the row for the first seedings and three kernels for the later seedings. The stands were thinned to one plant every 15 inches. The data obtained from this and succeeding experiments are shown in Table 2.

In 1916 22 varieties were grown. The dates of seeding were April 20, May 20, and July 7. It was planned to make a third seeding about June 20 and a fourth about July 20. The wet condition of the land, however, made it necessary to delay the third seeding until July 7, and because of this late date a fourth seeding was not made. The different seedings were made in single rows 132 feet long and 3.3 feet apart on uniform reclaimed river land that had not been previously cropped. The rate of seeding was three kernels every 15 inches in the row. The stands were thinned to one plant every 15 inches.

In 1917 19 varieties were grown. The dates of seeding were April 12, May 19, June 21, and July 16. The different seedings were made in single rows 82.5 feet long and 3.3 feet apart on fairly uniform upland where a crop of rye had been plowed under. The rye had been preceded by soy beans. The seedings were made in hills 3.3 feet apart and the stands were thinned to two plants per hill.

In 1918 14 varieties were grown. The dates of seeding were May 7, May 24, June 20, and July 19. Owing to unfavorable weather the earliest seeding was delayed beyond the date intended. The different seedings were made in single rows 66 feet long and 3.3 feet apart on well-drained, fertile, uniform upland that had been cropped to corn the previous year. The stand of the smaller varieties was one plant every 12 to 14 inches in the row and of the later, larger growing varieties one plant every 16 to 18 inches.

TABLE 2.—*Effects of seeding on different dates upon the germination, growth, and development of corn, in experiments conducted at Arlington Experimental Farm, near Washington, D. C., during the 6-year period from 1915 to 1920, inclusive.*

[The symb ol F indicates that the crop was killed by frost before reaching maturity. In 1918 the first (April) seeding, delayed by weather conditions, was actually made on May 7.]

Name of variety.	Number of days from—												Height of plants (feet).			
	Seeding to emergence.				Emergence to first silks.				Emergence to ripening.							
	Apr.	May.	June.	July.	Apr.	May.	June.	July.	Apr.	May.	June.	July.	Apr.	May.	June.	July.
Season of 1915:																
North western Dent	12	12	10	8	50	41	33	33	99	82	82	96	5.5	5.5	4.5	5.5
Brown County Yellow	11	12	10	8	50	43	35	33	99	82	83	96	6.3	6.3	5.3	5.7
U. S. Selection 133	12	12	10	8	50	45	37	41	107	86	85	98	7.0	7.3	7.5	7.5
Minnesota 13	12	12	10	8	50	45	36	37	107	86	85	98	7.0	7.3	7.0	7.5
Martens White Dent	13	12	10	8	53	46	37	42	107	86	85	98	5.7	6.3	6.5	6.0
Rustler White Dent	12	12	10	8	50	41	33	35	105	82	79	96	5.0	5.2	5.2	6.0
Australian White Flint	12	12	10	8	51	47	37	40	112	90	88	.....	6.5	6.0	5.7	6.0
Gehu Yellow Flint	13	12	10	8	41	39	30	31	104	80	78	93	3.7	4.0	4.0	3.5
Disco 90-Day	12	12	10	8	53	48	39	41	110	86	85	.....	6.0	6.0	5.5	6.0
Disco 85-Day	14	12	10	8	50	46	37	37	107	82	85	98	5.3	5.0	4.7	5.0
Blue Squaw Flour	13	12	10	8	41	39	31	31	99	80	76	91	4.0	4.2	4.5	3.5
Idaho Flint	16	14	10	8	56	45	39	41	112	86	85	.....	4.7	5.2	5.0	5.7
Cornforth Dent	14	12	10	8	50	43	33	31	105	82	78	F	5.2	5.2	5.0	5.7
Early Huron	15	12	10	8	58	51	40	41	112	90	90	F	6.5	6.2	6.2	7.2
Rocky Mountain Dent	16	12	10	8	56	48	39	41	112	90	88	F	7.2	6.2	6.7	7.0
Stickney Flint	16	12	10	8	56	51	40	41	112	93	88	F	5.5	5.7	6.5	6.0
Fairfield Yellow Dent	16	12	10	8	57	51	39	41	114	90	88	F	6.2	6.2	7.5	7.0
U. S. Selection 193	13	12	10	8	56	52	41	41	117	93	92	F	7.0	6.2	7.5	7.0
Davis Yellow Dent	14	12	10	8	58	54	44	43	118	93	92	F	7.5	8.7	9.0	7.2
Wilson White Cap	12	12	10	8	54	49	39	41	112	90	88	F	7.2	8.0	8.5	7.2
Long Island Yellow Dent	14	12	10	8	58	52	41	43	117	93	88	F	6.7	8.0	7.5	6.7
Woods Northern White Dent	13	12	10	8	60	57	46	45	119	98	93	F	6.5	8.2	7.5	7.0
100-Day Bristol	13	12	10	8	61	58	46	47	117	101	93	F	8.2	8.5	8.7	7.0
U. S. Selection 119	14	12	10	8	70	66	53	51	121	106	102	F	9.0	9.5	10.2	8.0
Average (24 varieties)	13	12	10	8	54	48	39	40	110	89	87	*a* 96	6.2	6.4	6.5	6.3
Season of 1916:																
North western Dent	15	9	....	7	54	48	....	35	89	84	.....	79	5.0	4.0	.....	4.0
Brown County Yellow	15	9	....	7	55	49	....	32	89	95	.....	79	5.0	4.0	.....	4.0
U. S. Selection 133	16	9	....	7	58	52	....	38	103	97	.....	83	6.5	4.0	.....	4.7
Minnesota 13	16	9	....	7	60	49	....	35	103	99	.....	83	6.5	4.0	.....	4.7
Martens White Dent	16	9	....	7	60	53	....	43	103	98	.....	83	5.5	3.0	.....	4.3
Rustler White Dent	15	9	....	7	53	48	....	35	89	99	.....	83	3.5	3.0	.....	4.0
Disco 90-Day	16	10	....	7	55	52	....	38	106	103	.....	83	6.3	4.5	.....	4.3
Disco 85-Day	16	10	....	7	58	51	....	38	105	101	.....	83	4.0	3.7	.....	5.3
Fulton	16	9	....	7	60	50	....	41	107	105	.....	88	5.3	4.0	.....	4.5
Cornforth Dent	15	9	....	7	55	48	....	31	89	105	.....	88	5.0	4.0	.....	4.7
Early Huron	16	9	....	7	66	61	....	40	107	108	.....	93	5.7	3.5	.....	5.5
Rocky Mountain Dent	16	9	....	7	69	63	....	45	107	112	.....	F	6.0	4.3	.....	6.3
Fairfield Yellow Dent	16	9	....	7	68	53	....	41	107	115	.....	F	5.7	4.5	.....	6.7
U. S. Selection 193	16	9	....	7	69	63	....	48	114	114	.....	F	5.7	4.5	.....	6.3
Davis Yellow Dent	16	9	....	7	71	64	....	41	118	115	.....	F	6.0	4.5	.....	6.5
Wilson White Cap	16	9	....	7	69	63	....	40	107	112	.....	F	5.5	5.0	.....	6.7
Long Island Yellow Dent	16	9	....	7	69	64	....	49	119	115	.....	F	5.5	4.7	.....	5.3
Woods Northern White Dent	16	9	....	7	75	66	....	50	122	113	.....	F	6.0	4.5	.....	6.0
100-Day Bristol	16	9	....	7	75	63	....	50	133	133	.....	F	6.0	5.0	.....	6.5

a Average of 9 varieties that matured. The same 9 varieties from the April, May, and June seedings averaged 104, 83, and 81 days, respectively.

TABLE 2.—*Effects of seeding on different dates upon the germination, growth, and development of corn, in experiments conducted at Arlington Experimental Farm, near Washington, D. C., during the 6-year period from 1915 to 1920, inclusive*—Continued.

Name of variety.	Number of days from—												Height of plants (feet).			
	Seeding to emergence.				Emergence to first silks.				Emergence to ripening.							
	Apr.	May.	June.	July.	Apr.	May.	June.	July.	Apr.	May.	June.	July.	Apr.	May.	June.	July.
Season of 1916—Con.																
U. S. Selection 120.	16	9	....	7	84	66	....	51	137	140	.....	F	6.0	7.0	.....	7.3
Laguna	18	11	....	7	91	73	....	58	F	F	.....	F	7.5	.....	.....	7.7
U. S. Selection 119.	17	10	....	7	87	70	....	55	157	140	.....	F	6.5	7.0	.....	6.5
Average (22 varieties)	16	9	....	7	66	58	....	42	110	109	.....	[b] 84	5.6	4.4	.....	5.5
Season of 1917:																
North western Dent	20	10	6	6	57	43	34	34	92	83	72	83	3.0	5.5	5.5	4.0
Brown County Yellow	20	10	6	6	57	43	35	34	92	83	72	83	3.0	5.0	5.5	4.5
U. S. Selection 133.	20	10	6	6	65	47	38	38	107	90	81	F	3.5	7.5	6.5	5.5
Minnesota 13	20	10	6	6	63	42	37	35	107	88	79	F	3.5	6.5	6.5	4.5
Martens White Dent	20	10	6	6	58	43	35	39	107	93	85	F	3.0	5.5	6.0	4.0
Rustler White Dent	20	10	6	6	63	47	40	37	107	93	85	F	3.0	5.7	5.5	4.0
Disco 90-Day	20	10	6	6	65	48	40	39	107	95	87	F	3.0	6.2	7.0	4.2
Fulton	20	10	6	6	64	46	39	38	107	98	87	F	3.0	5.7	6.5	5.2
Cornforth Dent	20	10	6	6	57	41	33	37	92	85	72	F	3.0	5.0	6.5	4.5
Early Huron	20	10	6	6	65	48	40	36	107	101	92	F	3.0	7.2	7.5	5.5
Rocky Mountain Dent	20	10	6	6	65	51	42	41	107	101	97	F	3.5	8.0	8.0	5.5
U. S. Selection 193.	20	10	6	6	65	48	43	41	107	101	97	F	5.0	8.0	8.0	5.7
Wilson White Cap.	20	10	6	6	68	48	43	40	107	101	92	F	5.0	8.0	8.0	5.7
Long Island Yellow Dent	20	10	6	6	71	51	44	41	112	108	101	F	5.5	8.5	8.0	5.7
Woods Northern White Dent	20	10	6	6	75	51	46	46	128	108	107	F	6.7	8.2	8.5	5.2
100-Day Bristol	20	10	6	6	77	55	47	47	131	115	108	F	7.5	10.0	9.0	6.0
U. S. Selection 120.	20	10	6	6	84	61	49	51	138	123	F	F	8.0	10.5	10.0	6.2
Laguna	20	10	6	6	96	70	61	67	145	133	F	F	8.0	12.0	10.5	5.7
U. S. Selection 119.	20	10	6	6	87	62	56	58	140	126	F	F	8.0	11.5	10.0	5.7
Average (19 varieties)	20	10	6	6	68	50	42	42	113	102	[c] 88	[d] 83	4.6	7.6	7.5	5.1
Season of 1918:																
North western Dent	10	10	8	7	42	40	38	34	82	81	82	.....	5.0	5.2	5.5	5.2
Cornforth Dent	10	10	8	7	41	36	37	33	79	78	85	.....	5.0	5.0	5.7	5.2
U. S. Selection 133.	10	10	8	7	48	45	45	40	89	86	.....	.....	5.7	6.0	6.2	5.7
Minnesota 23	10	10	8	7	47	43	42	33	87	81	82	.....	5.0	5.2	5.7	5.5
Martens White Dent	10	10	8	7	48	42	44	39	89	84	.....	.....	5.0	5.5	5.7	5.5
Disco 90-Day	10	10	8	7	49	46	47	40	92	88	.....	.....	5.7	6.0	6.5	5.7
Fulton	10	10	8	7	50	47	45	40	94	91	.....	.....	5.2	6.0	6.5	5.7
Early Huron	10	10	8	7	49	46	44	40	94	91	.....	.....	6.5	6.7	7.0	7.0
U. S. Selection 193.	10	10	8	7	54	50	47	44	101	93	.....	.....	6.5	7.2	7.0	7.0
Wilson White Cap.	10	10	8	7	49	49	46	45	96	92	.....	.....	6.5	7.2	7.2	7.5
100-Day Bristol	10	10	8	7	55	53	50	47	101	97	.....	.....	7.7	8.7	7.5	8.2
U. S. Selection 120.	10	10	8	7	62	58	56	52	105	110	.....	.....	8.7	8.5	9.0	8.2
Laguna	10	10	8	7	73	72	67	65	127	.....	.....	.....	9.2	8.2	9.0	8.5
U. S. Selection 119.	10	10	8	7	69	64	59	62	111	113	.....	.....	8.5	8.2	9.0	8.5
Average (14 varieties)	10	10	8	7	53	49	48	44	96	91	.....	.....	6.4	6.7	7.0	6.7
Season of 1919:																
White Ree	14	10	6	6	45	33	41	....	.....	.....	81	71	4.2	4.2	3.7	3.3
Cornforth Dent	14	10	6	6	51	36	41	....	.....	.....	84	83	6.0	5.0	5.5	5.2
North western Dent	14	10	6	6	52	37	44	....	.....	.....	86	86	5.0	5.0	5.5	5.2

[b] Average of 11 varieties that matured. The same 11 varieties averaged 99 days from both the April and May seedings.

[c] Average of 16 varieties that matured. The same 16 varieties averaged 107 and 97 days from the April and May seedings, respectively.

[d] Average of 2 varieties that matured. The same 2 varieties averaged 92, 85, and 72 days from the April, May, and June seedings, respectively.

TABLE 2.—*Effects of seeding on different dates upon the germination, growth, and d ment of corn, in experiments conducted at Arlington Experimental Farm near ington, D. C., during the 6-year period from 1915 to 1920, inclusive*—Continue

Name of variety.	Number of days from—												Height of pla (feet).		
	Seeding to emergence.				Emergence to first silks.				Emergence to ripening.						
	Apr.	May.	June.	July.	Apr.	May.	June.	July.	Apr.	May.	June.	July.	Apr.	May.	Ju
Season of 1919—Contd.															
Martens White Dent	14	10	6	6	56	42	45	....	.....	.....	91	96	6.5	6.0	6
U. S. Selection 133	14	10	6	6	56	40	46	....	.....	.....	96	98	6.5	6.5	6
Wilson White Cap	14	10	6	6	61	47	46	....	.....	.....	105	101	7.5	7.5	8
Fulton	14	10	6	6	57	43	46	....	.....	.....	97	108	7.0	7.0	6
U. S. Selection 193	14	10	6	6	60	50	51	....	.....	.....	111	F	8.0	8.0	7
100-Day Bristol	14	10	6	6	61	51	52	....	.....	.....	115	F	8.2	8.7	8
U. S. Selection 120	14	10	6	6	68	60	59	....	.....	.....	120	F	8.7	8.7	9
Laguna	14	10	6	6	80	65	67	65	.....	.....	127	F	11.0	10.2	11
U. S. Selection 119	14	10	6	6	71	61	62	59	.....	.....	122	F	9.7	9.5	9
Average (12 varieties)	14	10	6	6	60	47	50	....	.....	.....	103	e 92	7.6	7.2	7
Season of 1920:															
Cornforth Dent	20	9	6	5	56	47	39	38	100	94	76	87	3.7	5.5	5
North western Dent	20	9	6	5	58	47	40	39	100	94	79	87	3.7	5.0	5
U. S. Selection 133	20	9	6	5	65	52	43	43	109	97	86	92	6.2	7.0	7
San Miguel	20	9	6	5	67	54	46	49	113	100	105	97	6.2	6.5	7
Fulton	20	9	6	5	67	52	43	44	112	100	91	97	6.5	7.5	8
100-Day Bristol	20	9	6	5	72	62	53	50	119	111	114	F	8.2	9.2	9
U. S. Selection 119	20	9	6	5	80	68	57	57	125	121	122	F	9.5	10.2	10
Laguna	20	9	6	5	90	77	65	66	130	133	F	F	10.5	10.7	10
Average (8 varieties)	20	9	6	5	69	57	48	48	113	106	f 96	g 92	6.8	7.7	7

SUMMARY OF THE DATA FOR THE YEARS 1915, 1917, 1919, AND 1920 (1916 AND 1918 NOT INCLUDE

Date of seeding (on approximately the 20th of the month).	Number of seedings.	Number of days from—		
		Seeding to emergence.	Emergence to first silks.	Emergence to ripening.
April	63	17	63	h 112
May	63	10	51	h 99
June	63	7	45	i 93
July	63	6	43	j 91

e Average of 7 varieties. The same 7 varieties averaged 91 days from the June seeding.
f Average of 7 varieties. The same 7 varieties averaged 111 and 102 days for the April and M ings, respectively.
g Average of 5 varieties. The same 5 varieties averaged 107, 97, and 87 days for the April, May, seedings, respectively.
h Data from 51 seedings.
i Data from 59 seedings.
j Data from 23 seedings. These 23 seedings were of the earliest maturing varieties. The same required 103, 87, and 85 days from the April, May, and June seedings, respectively.

In 1919 12 varieties were grown. The dates of seeding were 21, May 20, June 20, and July 21. The different seedings were in single rows 66 feet long and 3.3 feet apart on uniform recl river land that had been cropped to corn the previous year. stand of the earlier small varieties was one plant every 10 inc the row and of the larger varieties one plant every 16 inches.

In 1920 eight varieties were grown. The dates of seeding were April 20, May 20, June 24, and July 20. The different seedings were made in single rows 66 feet long and 3.3 feet apart on uniform reclaimed river land that had been cropped to corn the previous year. The stands varied from one plant every 10 inches for the smaller varieties to one plant every 16 inches for the larger varieties.

A summary of the data obtained from the experiments conducted in 1915, 1917, 1919, and 1920 is shown in Table 2. Data from the experiments conducted in 1916 and 1918 are not included in this summary, as only three seedings were made in 1916, and in 1918 two of the seedings were made in May.

RESULTS OBTAINED.

In all the experiments there was a consistent decrease in the number of days from seeding to emergence as the date of seeding was delayed, although frequently the June and July seedings showed such slight differences that they were not recorded. The number of days from emergence to silking and from emergence to ripening consistently decreased except in the July seedings, which tended to show increases as compared with the June seedings. The maximum heights of most of the varieties were attained in the June seedings. The May seedings ranked second, the July seedings third, and the April seedings fourth in height of stalks.

EFFECTS ON GERMINATION.

When sown early the short-season northern varieties came up sooner than the varieties from the Central and Southern States. When sown later the differences in this respect usually were not apparent; where differences occurred the early-maturing northern varieties were found to be the first to come up. The results indicate that these northern-grown varieties are capable of starting growth at lower temperatures than the later maturing varieties of the Central and Southern States. Germination, as would be expected, was much more rapid from the later than from the earlier seedings. Seeds sown in April required an average of 17 days to come up to a stand, whereas those sown in July were as far advanced 6 days after seeding.

EFFECTS ON HEIGHT AND RATE OF GROWTH.

The average height of stalk and the average daily increase in height in the different seedings are shown in Table 3.

The total height and the daily increase in height were greatest from the June seeding. The total height was greater from the May seeding than from the July seeding, but the rate of growth was slower. The least height and the slowest rate of increase resulted from the April seeding.

TABLE 3.—*Total height and average daily increase in height of corn at the Arlington Experimental Farm, near Washington, D. C., when planted on different dates in 1915, 1917, 1919, and 1920.*

Date of seeding.	Emergence to full growth (days).	Height of stalks (inches).	
		Total.	Average daily increase.
Apr. 19	63	75.6	1.20
May 20	51	86.4	1.69
June 21	45	88.8	1.97
July 20	43	76.8	1.79

EFFECTS ON DEVELOPMENT.

The number of days from emergence to first silks decreased as the date of seeding was delayed from April to July. The number of days from emergence to ripening also decreased except in the case of the July seedings. These showed an increase as compared with the June seedings. Development to the silking stage was more rapid as the date of seeding was delayed. The plants from the April seeding required 63 days from emergence to reach the same stage of development which those from the July seeding attained in 43 days.

The duration of the pollen-shedding period depended upon the degree of inherent variation within the variety, the lack of uniformity in coming up, the amount of suckering, the variation in the fertility of the soil, and weather conditions. How these various factors might influence the duration of pollen shedding in a variety is evident and need not be treated in detail. Except under unusual conditions, the experiments indicate that the duration of this period is longer in plants from the earlier seedings than in those from the later seedings. The average for the plants from the April seedings was 22 days; May, 19 days; June, 18 days; and July, 17 days.

CORRELATION OF EFFECTS.

It is of interest to know how closely the difference in number of days between the dates of seeding corresponds with the differences between dates of emergence, dates of first silking, and dates of ripening. The average results from all the experiments are shown in Table 4.

As the date of seeding was delayed the differences in the time of emergence, silking, and ripening more nearly approximated those in the date of seeding.

In the comparison of April and May seedings a difference of 32 days in time of seeding represents a gain of 14 days in time of ripening. May 20, however, is later than the usual date of seeding in

the vicinity of Washington, and this gain in time of maturity does not represent the gain of early over normal seedings. In this connection, some comparisons of early seedings made in April with seedings made at more nearly the normal date of seeding (May 1 to 15) will be of interest.

TABLE 4.—*Differences in the dates of seeding and the resulting differences in the dates of emergence, silking, and ripening of corn in experiments conducted at the Arlington Experimental Farm, near Washington, D. C., during the 6-year period from 1915 to 1920, inclusive.*

Average dates of seeding.	Seedings compared.	Years of data.	Number of days difference in—			
			Seedings.	Emergence.	Appearance of first silks.	Ripening.
Apr. 18 May 20	April and May	1915, 1916, 1917, and 1920	32	25	14	14
May 20 June 22	May and June	1915, 1917, and 1920	33	30	22	23
June 21 July 19	June and July	1915, 1917, 1918, and 1920	28	27	26	.....

Data from such comparisons made in 1917, 1919, and 1920 are shown in Table 5. In 1917 the experimental plats were located on fairly uniform upland. The seeding made on April 12 was on land that had been cropped to soy beans the previous year, followed by rye that had been plowed under preparatory to seeding corn. The plat seeded on May 14 was on land that had been in sod the previous year. The two plats, however, were sufficiently similar to permit reliable comparisons in respect to the characters dealt with in Table 5. In 1919 and 1920 all the seedings were made in adjacent or neighboring plats on uniform reclaimed river land that had been previously cropped to corn.

The results presented in Table 5 show that in the season of 1917 plants from seedings made a month earlier than normal were about a week earlier in silking than plants from normal seedings. In 1919 the gain in earliness was less than a week. In 1920 a difference of 17 days between seedings resulted in a gain of 7 to 9 days in the time of silking. The differences in the time of silking correspond fairly closely with the differences in the time of ripening and can be determined more readily and with a greater degree of accuracy. The data available indicate that the differences at the time of ripening are slightly less than at the time of silking.

TABLE 5.—*Differences in the time of emergence and in the silking of corn seeded on early and normal dates at the Arlington Experimental Farm, near Washington, D. C., in 1917, 1919, and 1920.*

Variety.	Dates of seedings.	Number of days difference in—		
		Seedings.	Emergence.	Appearance of first silks.
Season of 1917:				
Northwestern	Apr. 12 and May 14.	32	25	14
U. S. Selection 133	do	32	25	9
Early Huron	do	32	25	8
Rocky Mountain Dent	do	32	25	13
100-Day Bristol	do	32	25	4
U. S. Selection 119	do	32	25	3
Season of 1919:				
White Ree	Apr. 9 and 30	21	12	5
U. S. Selection 133	do	21	12	6
U. S. Selection 193	do	21	12	6
U. S. Selection 119	do	21	12	0
White Ree	Apr. 9 and May 14	35	22	5
U. S. Selection 133	do	35	22	7
U. S. Selection 193	do	35	22	10
U. S. Selection 119	do	35	22	3
White Ree	Apr. 30 and May 14.	14	9	0
U. S. Selection 133	do	14	9	1
U. S. Selection 193	do	14	9	3
U. S. Selection 119	do	14	9	3
White Ree	Apr. 21 and May 14.	23	18	3
U. S. Selection 133	do	23	18	7
U. S. Selection 193	do	23	18	6
U. S. Selection 119	do	23	18	8
Season of 1920:				
U. S. Selection 133	Apr. 20 and May 7	17	9	9
U. S. Selection 119	do	17	9	7

SUMMARY.

The results of the experiments at the Arlington Experimental Farm, near Washington, D. C., are as follows:

(1) The germination of corn increased in rapidity as the date of seeding occurred later.

(2) The total growth of stalk was greatest from the seedings in June and May. The rate of growth was most rapid from the June and July seedings. The total growth was least and rate of growth slowest from the April seedings.

(3) Development was more rapid in the later than in the earlier seedings.

(4) The number of ears per stalk, the size of the ear, and the amount of suckering bore no consistent relation to the date of seeding.

(5) The pollen-shedding period was longer in plants from the early seedings than those from the later seedings.

(6) Seedings earlier than normal resulted in slight gains in the date of silking.

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WM. A. TAYLOR, Chief

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DEVELOPMENT OF WILT-RESISTANT TOMATOES.

By Fred J. Pritchard, *Physiologist, Office of Cotton, Truck, and Forage Crop Disease Investigations.*

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PREVALENCE AND CHARACTERISTICS OF TOMATO WILT.

Tomato wilt (*Fusarium lycopersici*) causes an estimated annual loss of more than 115,000 tons of tomatoes in the Middle Atlantic, Gulf, and lower Mississippi Valley States.[1] As it is prevalent also in the Ohio River Valley, in California, and in parts of Colorado and Utah, it reduces the yield even more than is expressed by these figures. This loss can and should be overcome by the use of wilt-resistance varieties.

Wilt is characterized in its early stage by a wilting of the plant and an upward and inward rolling of the leaves (Pl. I, fig. 1). Later the lower and finally the upper leaves turn yellow and slowly die. When a branch is thus deprived of its foliage it dies back from the tip, turns brown, and shrivels. Some of these final changes and the varied progress of the disease in different branches are shown in

[1] The loss from wilt in the canning crop of tomatoes estimated by the Plant-Disease Survey of the Bureau of Plant Industry from reports of State and Federal pathologists for the year 1918 was 115,000 tons, but this did not cover the whole area infested by wilt nor did it include the loss in the crop grown for trucking and home gardening.

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Plate I, figure 2. Not infrequently whole fields of plants wilt in this manner (Pl. II, fig. 1) and finally succumb to the disease.

In cross and longitudinal sections of infected stems (Pl. III) there is a dark-brown discoloration in the woody area between the pith and the bark, but the pith itself is usually normal. The presence and position of this discoloration are important diagnostic characters which help to distinguish the wilt from another similar disease known as southern bacterial blight (bacterial wilt).

Not only the stems and leaves but also the fruits are infected by wilt (Pl. II, fig. 2). By means of the discolored tissues infection can be traced through the fruit stems into the fruit and even to the seed.

Yearly discoveries of wilt where it has never previously been found indicate that it is either continually spreading or is not infrequently present where it has never been reported. Observations and reports show that both of these conditions obtain.

It is probable that wilt will eventually spread over the greater part of the tomato-canning areas if not prevented by the use of resistant varieties. Although the wilt fungus may not thrive so well in the North as it has in the South, the fact that it is continually spreading in some of the more northern States, such as New Jersey, Indiana, and Ohio, and has even been found in Michigan, New York, and Massachusetts, shows that it is seemingly capable of thriving in the more important tomato-canning regions of the United States.

Wilt is carried to some extent by the seed, but not so commonly as the high percentage of fruit infections in wilt-infested fields would seem to indicate. The fungus passes through the fibro-vascular bundles of the fruit to the seed and often invades the cells surrounding the seed coat. Were it not for the removal of these cells through fermentation and washing of the seed in the seed-saving process the infection of plants through the seed would be much more common. The fungus-bearing particles separated from the seed by fermentation frequently adhere to it, however, and thus become a source of infection for the plant and a means of more widespread distribution for the fungus. Infection of plants through the seed would be more common if tomato seed was produced commercially in badly wilt-infested regions.

The most common method of spreading wilt is through infected seedlings. Tomatoes are very generally grown in seed beds and are transplanted to the field when danger of frost is past. Not infrequently the fungus occurs in the seed-bed soil in wilt-infested regions. As such soil is usually rich in organic matter the fungus multiplies rapidly and soon invades the roots of the seedlings. Although this causes a discoloration of the rootlets, the grower, who not infrequently is unfamiliar with plant diseases, usually fails to

recognize it and either plants or sells the seedlings. Wherever such seedlings are used they spread the disease. In the Middle West the practice of using tomato plants grown in Maryland, Delaware, and the Southern States when there is a shortage of locally grown plants is attended with this danger.

Although wilt does not at present cause so much loss as tomato leaf-blight (*Septoria lycopersici*), it is much worse than blight wherever the soil becomes thoroughly infested with the wilt fungus. It therefore threatens the future success of the tomato-canning industry and should by all means be brought under control.

The only means of controlling wilt successfully has been developed in recent years. As the wilt fungus lives in the soil and invades the tomato plant through its roots, it lies beyond the reach of chemical sprays, such as Bordeaux and other mixtures commonly used for the control of fruit and foliage parasites. It multiplies rapidly in the tomato plant, as it has no competition for its food supply, and it becomes thoroughly distributed through the soil with the plowing under of dead vines. If a piece of wilt-infested land be used successively for growing tomatoes it soon becomes so full of the fungus that ordinary varieties of tomatoes can not be grown on it. Rotation of crops forces the wilt fungus to compete with other fungi for its food and therefore reduces it to a minimum, but so far as known does not eradicate it, as it is capable of living long periods, if not indefinitely, on the organic matter in the soil. Treating the soil with chemicals for the control of wilt has not given results of economical value. Large quantities of lime retard its development,[2] but do not otherwise inhibit its activities. The only successful means of controlling wilt is through the development of resistant varieties.

DEVELOPMENT OF RESISTANT VARIETIES.

SELECTION OF MATERIAL.

It is necessary in breeding for wilt resistance to have at least one variety with some resistance to the disease as a basis for selection or crossing. If it possesses only moderate resistance but exhibits it in diverse degree in individual plants, it will serve as a starting point. If it possesses considerable resistance but lacks yield and quality, its resistance can be combined with other desirable qualities by crossing. If, in addition to partial resistance, it is characterized by superior yield and quality of fruit, it will facilitate the work by eliminating crossing and the breaking up of the type.

In searching for suitable material for resistant foundation stock the writer has tested the best canning varieties, the extra large

[2] Edgerton, C. W., and Moreland, C. C. Tomato wilt. La. Agr. Exp. Sta. Bul. 174, 54 p., 19 fig. 1920. Literature cited, p. 54.

fruited varieties, the more distantly related small-fruited varieties, and the varieties recommended in the literature and in seedsmen's catalogues for resistance to tomato diseases. Some of these were tested in 1915 and others in succeeding years.

PREPARATION OF THE BREEDING PLATS.

In order to have satisfactory breeding plats for making the tests, a piece of sandy soil and a piece of clay loam upland on the Arlington Experimental Farm, near Washington, D. C., were thoroughly inoculated with the wilt fungus. This was done by sterilizing chopped straw in a large autoclave, spraying it with spores from a pure culture of the fungus, and after about a month disking it into the surface soil. A good covering of inoculated straw was thus added to the soil for three successive years. Plowing under this straw and the dead infected vines soon thoroughly inoculated the soil with the fungus.

To increase further the opportunity for infection, during the first two years the seed was soaked before planting in a suspension of Fusarium spores and sown in flats containing wilt-infested soil. Infested soil was also used in the flats to which the seedlings were transplanted and in the holes in which they were set in the field; also pure cultures of the fungus were mixed with the soil in the flats and with the soil around the roots of the plants in the field.

As wilted susceptible vines add large quantities of the fungus to the soil while resistant vines do not, the infected vines were cut into small pieces and distributed over the field to help maintain uniform infestation. This seemed desirable, because in greenhouse experiments with tomato wilt the writer found that even when all plants are exposed to infection the percentage of those infected varies with the quantity of inoculum used. Although the fungus was already thoroughly distributed through the soil, its unequal accumulation in certain parts through the plowing under of susceptible vines in one place and of resistant vines in another, if not corrected, would very likely have affected experimental results.

METHOD OF SELECTION.

Selections from two classes of material have been made: (1) Those of apparently resistant plants from wilt-infested fields, and (2) those of resistant strains from these selected plants.

The original selections were made in the worst wilt-infested areas that could be found, and though not always free from wilt they were much freer from it than the plants immediately surrounding them.

The seed from each plant was harvested separately and tested in progeny rows. These progeny rows or strains were graded for yield and quality of fruit and for wilt resistance. Those inferior to the

FIG. 1.—EARLY STAGE OF TOMATO WILT.

FIG. 2.—LATE STAGE OF TOMATO WILT.

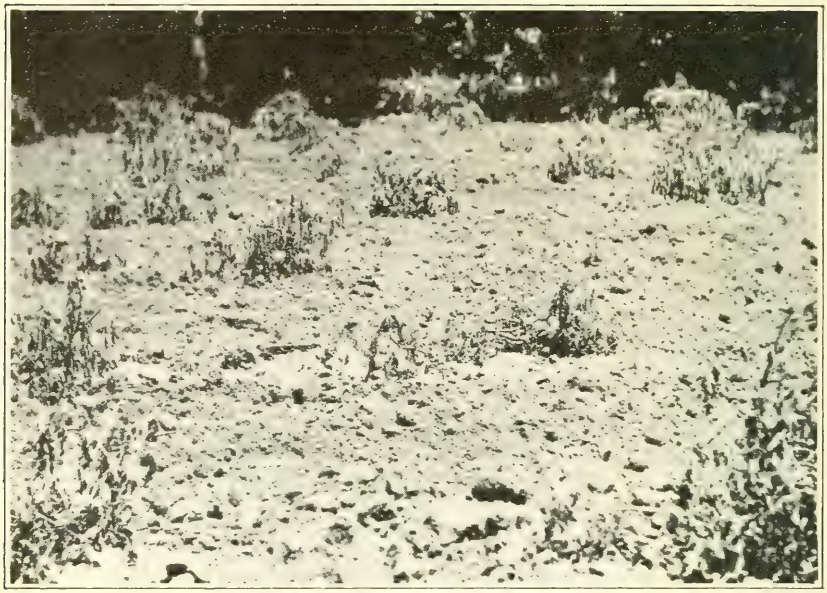


FIG. 1.—FIELD OF WILTED TOMATOES.

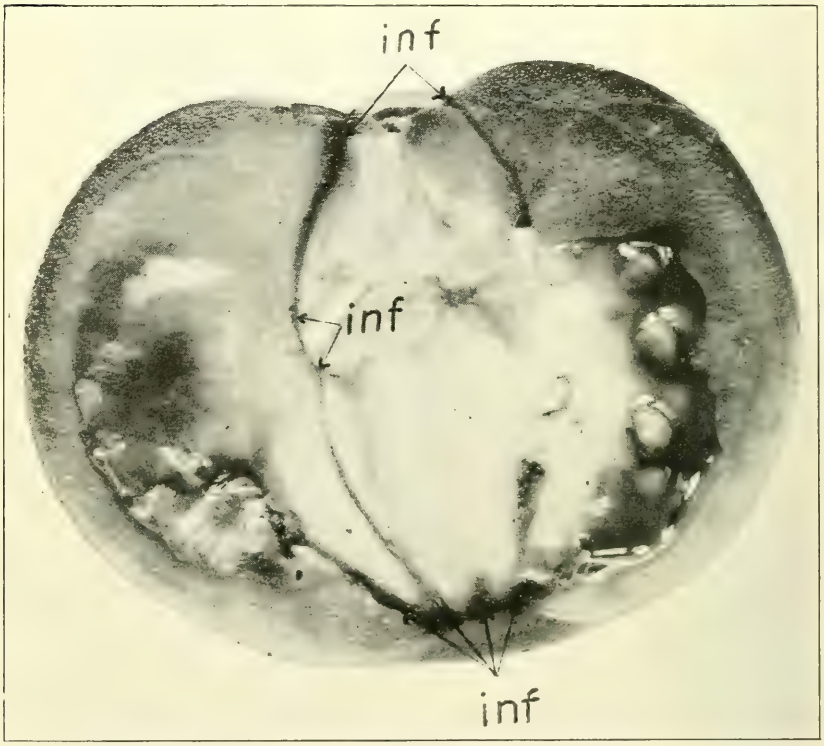
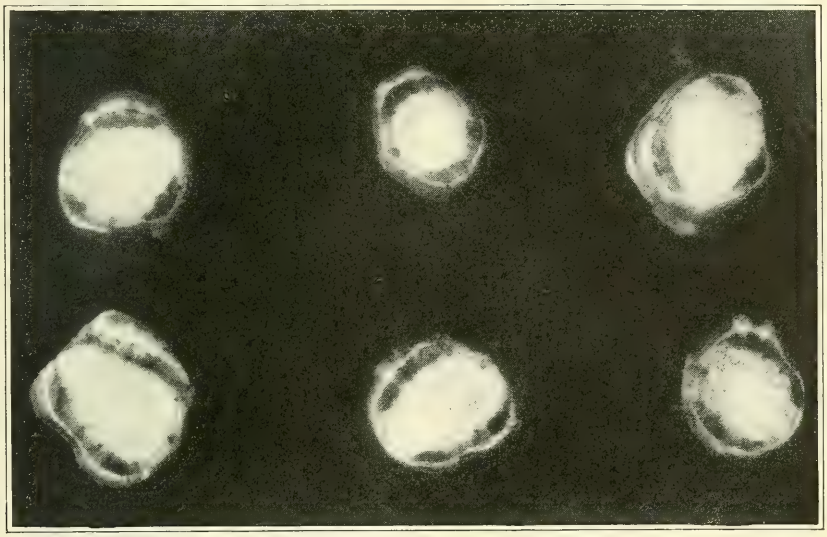
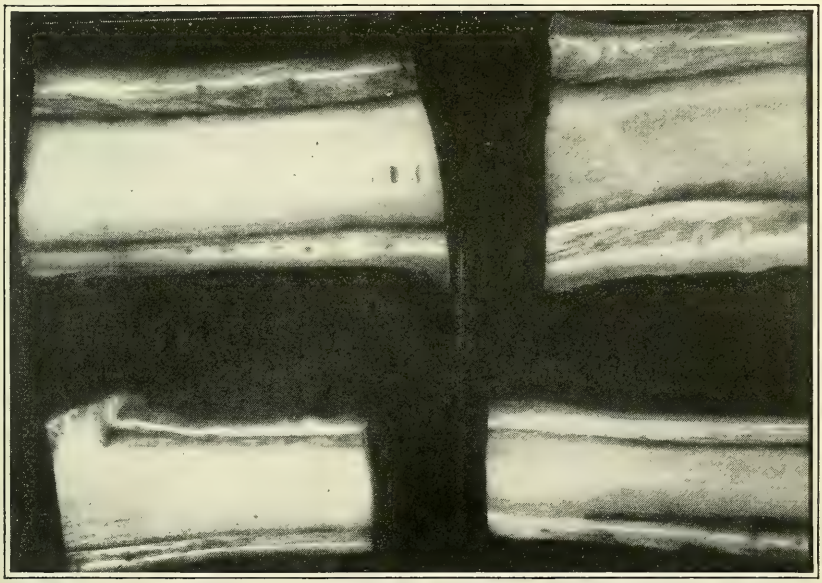


FIG. 2.—WILT-INFECTED TOMATO FRUIT.

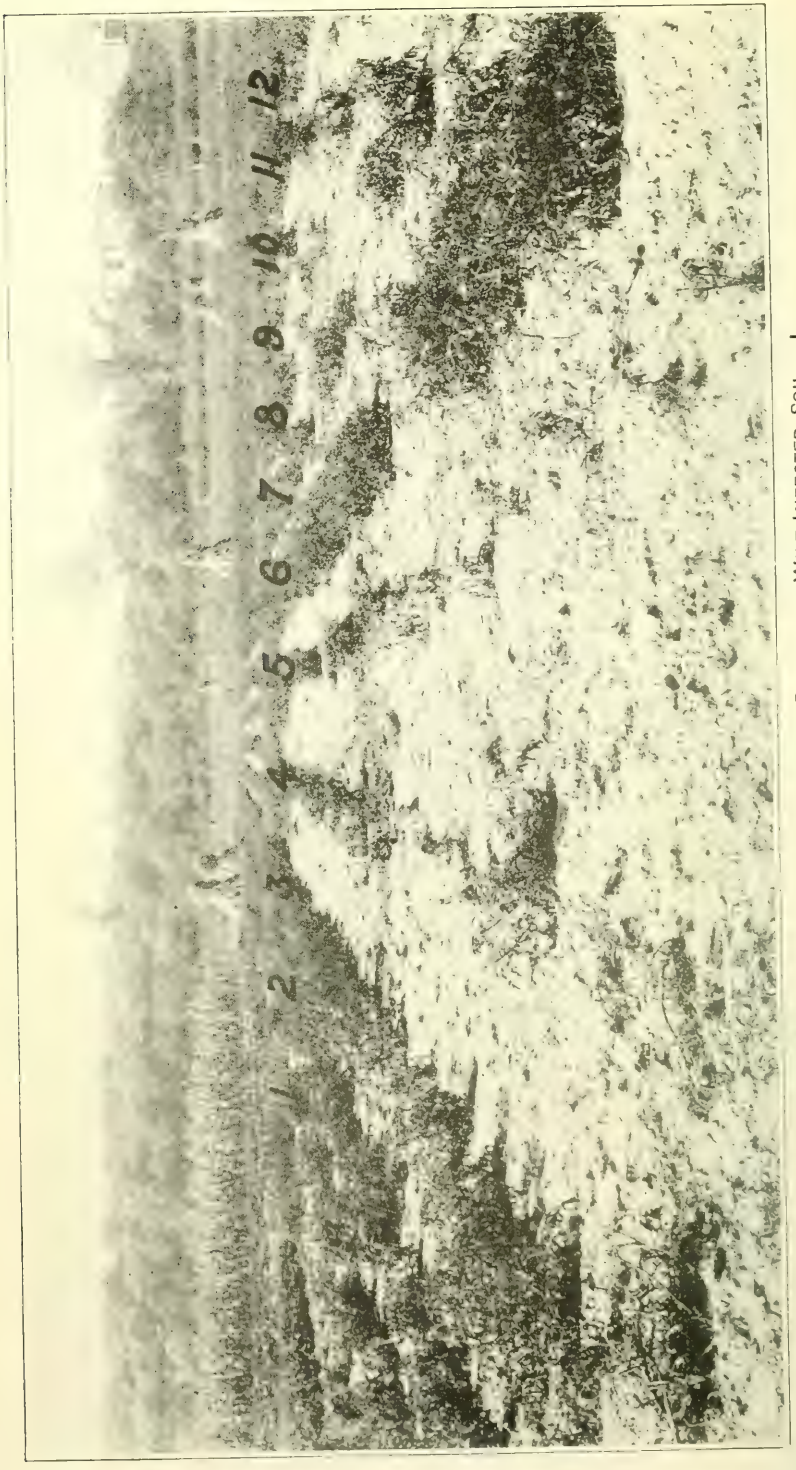
Note the dark-brown discoloration of the vascular tissues marked "inf."





CROSS AND LONGITUDINAL SECTIONS OF WILT-INFECTED TOMATO STEMS.

Note the dark-brown wilt-infected areas between the pith and the bark.



BEHAVIOR OF VARIETIES OF TOMATOES GROWN ON WILT-INFECTED SOIL. I.

Row 1, Norton; selection from Stone; row 2, selection from Greater Baltimore; row 3, Louisiana Wilt Resistant; row 4, Earliana; row 5, Bonny Best; row 6, Duke of York; row 7, Early Detroit; row 8, Ponderosa; row 9, Greater Baltimore.

best commercial varieties in quality of fruit were discarded without regard to other qualities. The most promising strains remaining were tested in subsequent years by repeated plantings on wilt-infested land beside the best commercial varieties, beside the most wilt-resistant varieties, and beside the best strains previously obtained by this method.

As it is difficult to determine accurately the degree of infection in wilted plants, the writer has graded the resistance of strains by a combination of characters correlated with the degree of infection, viz, the percentage of infected plants, the percentage of dead plants, and the yield of fruit.

The percentage of infected plants is correlated with the degree of infection in highly resistant material and is therefore useful in determining resistance when no plants die and when marked fluctuations in yields occur from variations in the environment.

The percentage of dead plants is useful in making selections from very susceptible material in which all or nearly all plants become infected and varying percentages die.

The yield of fruit is inversely correlated with the degree of infection in both resistant and susceptible varieties or strains. It is therefore useful in making selections for wilt resistance, but its exclusive use for this purpose is likely to lead to erroneous conclusions, as yields are often affected by other factors than wilt, and early susceptible varieties, such as Earliana and Texas Bell, partially freed from the effects of the disease because of the low soil temperature in the early part of the season, not infrequently produce a large part of their crop before they are killed by wilt.

Yields in these preliminary tests were not determined from actual weights of fruit but from general appearences; in fact, the differences were great enough to be easily distinguishable without the use of weights.

When the three characters, percentages of infected plants, percentage of dead plants, and yield of fruit, are judiciously used they furnish a fairly effective and rapid means of determining resistance.

VARIETAL RESISTANCE.

The only naturally wilt-resistant varieties of tomatoes having fruit of fair size and quality found by the writer are the Duke of York and the Buckeye State. In type of fruit and vine and in resistance to wilt they appear to be one variety under two names. Livingston's Globe possesses some resistance, enough, in fact, to be of economic importance, but it is not so resistant as the varieties just mentioned. Although the Duke of York and the Buckeye State produce large fruit it is rather hard, especially at the stem end, and has a large

green core. They are suitable varieties for crossing, but not very promising for selection.

A comparison of the resistance of the Duke of York and several selected varieties and commercial varieties may be seen in Plates IV and V. In Plate IV, rows 1, 2, and 3, in the foreground, are varieties that have been selected for resistance to wilt, while row 6 is the Duke of York, a naturally resistant variety. In Plate V, rows 1, 3, and 5 are the Marvel, a selected resistant variety, and rows 2 and 4 are susceptible commercial varieties. The photograph reproduced in Plate V was taken at the end of the season after the crop was harvested. Although the Marvel vines were somewhat defoliated by worms and therefore were less conspicuous than they would otherwise have been, they were still green while the others were dead.

No variety yet tested by the writer has been immune to wilt. The Duke of York, Buckeye State, and several varieties selected for resistance to wilt possess a high degree of resistance, but when grown on heavily infested soil having a temperature of 80° to 85° F. most of the plants show at least a trace of infection in roots or stems.

The comparative resistance of varieties tested by the writer in 1915, 1918, and 1919 are shown in Table 1. As a complete record was not made of the percentages of plants killed in 1916 and 1917, the results for these years are omitted from the table.

Infection was determined by cutting the stems with a knife and noting the color of the tissue between the bark and the pith. Quite thorough cutting was often necessary to find a trace of the disease in plants of the resistant varieties; in fact, some of them were free from it. Whenever the faintest symptom of the disease could be found in the tissues the plant was recorded as infected. Comparisons of the data in Table 1 should be limited to varieties grown in the same field and year. The conditions in different fields and in different years were not similar and therefore did not produce comparable results.

In the variety test for 1915 there was little difference among the varieties in the percentage of plants infected but considerable difference in the percentage of plants killed by wilt. The Louisiana Wilt-Resistant made the best and the Willis variety the poorest record, but in subsequent years the Duke of York and the Buckeye State gave approximately as good results as the Louisiana Wilt-Resistant variety. The Red Majestic and the Enormous made approximately as good records as the Duke of York and the Crimson Cushion for both percentages of plants infected and of plants killed; but the infected plants of the Red Majestic and the Enormous were small, nearly dead, and destitute of fruit, while those of the Duke of York produced about an average crop and those of the Crimson Cushion about a tenth or an eighth of a crop. The degree of infection there-

fore was not fully measured in the Red Majestic and the Enormous by the percentage of dead plants. It was more closely related to the appearance of the crop and quantity of fruit produced. The percentage of dead plants in the other varieties corresponded fairly closely with the degree of infection.

TABLE 1.—*Comparative susceptibility to wilt of different varieties of tomatoes when grown on uniformly wilt-infested soil at the Arlington Experimental Farm, Va., in 1915, 1918, and 1919.*

[I=infected; K=killed.]

Variety.	Comparative susceptibility.													
	Field 1.						Field 2.				Field 3.			
	1915		1918		1919		1918		1919		1918		1919	
	I	K	I	K	I	K	I	K	I	K	I	K	I	K
	P.ct.	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*
Louisiana Wilt-Resistant	87	1												
Duke of York	92	6												
Crimson Cushion	92	6												
Red Majestic	98	6												
Enormous	84	8												
Matchless	100	12			100	63			100	0				
Merveille des Marchés	94	16												
Perfection	92	24			100	65			100	88				
Ponderosa	100	24												
Greater Baltimore	100	28			100	72			94	25	68	10	69	44
Texas Bell	98	34												
Trophy	99	35												
Tres Hative de Pleine Terre	100	38												
Reine des Hative	100	40												
Stone	100	44	96	57	91	72			81	44	88	31		
Willis	100	100												
Marvel			2	0	81	0	40	0			6	0	25	0
Columbia			40	0	97	3								
Norton			43	0	87	0	42	0	66	0	15	0	19	0
Arlington			53	0	89	0	60	0	67	0	35	0	25	0
Tennessee A 16-2			75	0							60	0		
Burbank			100	25										
Mississippi Girl			100	68							75	0		
John Baer			100	94										
Mansfield Tree					81	0								
Louisiana Red					91	0							27	0
Louisiana Pink					97	0							75	0
Livingston's New Globe					94	6							100	0
Livingston's Globe					96	4			100	6				
Comet					100	13			100	31				
Success					100	0			100	50				
Earliana					100	38					100	38		
Grand Rapids Forcing					100	63								
Carter's Sunrise					100	69	56	0	100	75				
Red Currant							69	0						
Royal Red					100	56			100	93			88	38
Delaware Beauty					100	81			100	81			89	41
Red Cherry							94	75						
Early Jewel									100	88				
Red Head					100	94			100	100			94	56
Bonny Best					100	100					94	38		

In 1918 and 1919 the Marvel, Columbia, Norton,[3] and Arlington, wilt-resistant varieties developed by the writer, the Louisiana Red and Louisiana Pink, wilt-resistant varieties developed by Edger-

[3] The Norton, as will be explained later, was developed in cooperation with Mr. J. B. S. Norton, of the University of Maryland.

ton, and the Tennessee A 16–2, a wilt-resistant variety developed by Bain and Essary, were almost free from wilt; while the John Baer, Greater Baltimore, Stone, Royal Red, Delaware Beauty, Early Jewel, Red Head, and Bonny Best were nearly destroyed by the wilt. Moreover, the differences were much greater than the figures in Table 1 show.

Livingston's Globe and Livingston's New Globe possess considerable resistance to wilt, but not so much as the more highly developed resistant varieties.

The Mansfield Tree tomato resisted the disease fairly well in the one test made, but produced little fruit. It is by no means certain that it possesses as much resistance as the results of this test indicate. The Success and the Mississippi Girl gave good results in one test, but poor results in another.

From the results of these tests it is not surprising that the Bonny Best, one of the most productive varieties grown in the Middle Atlantic and Middle Western States, dies so rapidly in many places in the South. No different results could be expected from so susceptible a variety. The John Baer, Early Jewel, Royal Red, Delaware Beauty, Red Head, and Willis would probably do no better.

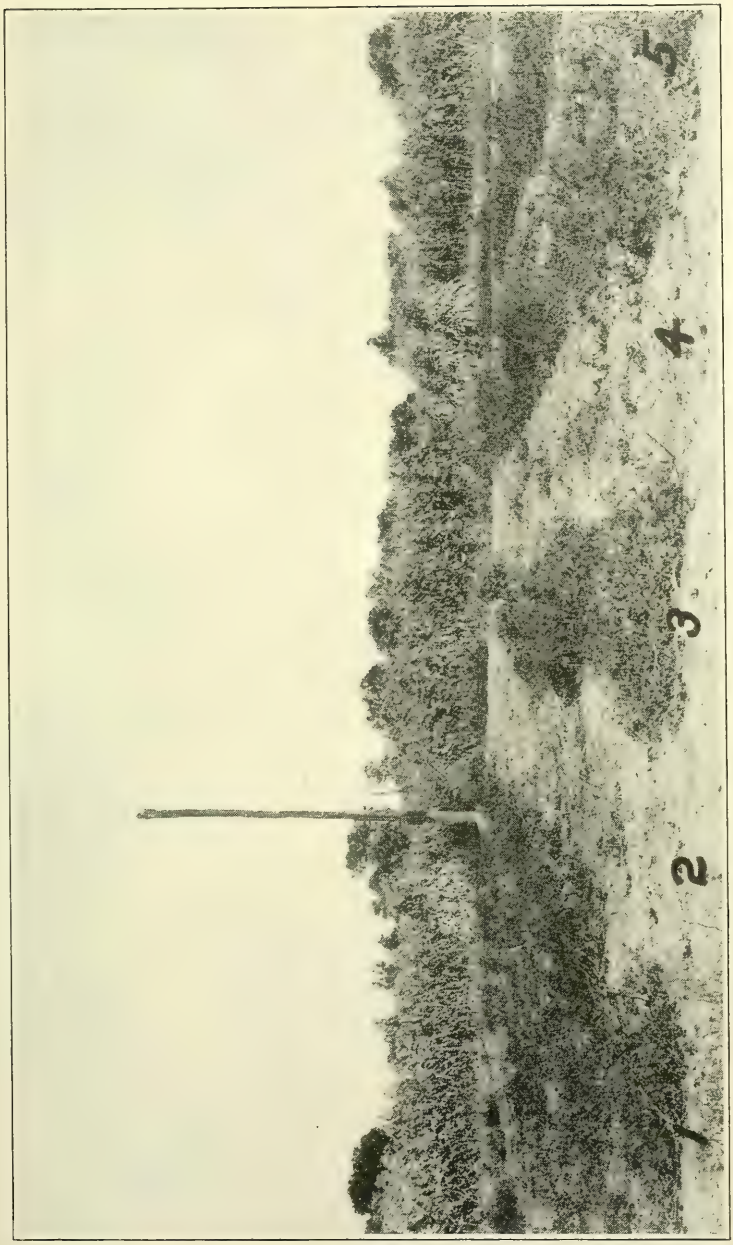
INTRAVARIETAL VARIATION.

Most varieties of tomatoes differ little from one another in the wilt resistance possessed by their individual plants. Very susceptible varieties, such as the Bonny Best, Delaware Beauty, John Baer, and Red Head, usually show about the same variation in intravarietal resistance as the fairly resistant varieties, Livingston's Globe, Duke of York, and Buckeye State. A few varieties, such as Stone, Greater Baltimore, and Merveille des Marchés, possess a much wider range of intravarietal resistance than the average. By selecting and testing a considerable number of plants from these varieties strains can be obtained that transmit a high degree of resistance to their progeny.

BEHAVIOR OF SELECTIONS.

Most plants selected for resistance to wilt transmit to their progeny no more resistance than is possessed by their parent varieties. A few excel in this respect, but their number is very small. Moreover, these few, even when selected from the same variety, differ in the degree of resistance they transmit.

Selections from a variety that transmits about the same degree of resistance to all its individual plants seldom transmit increased resistance. They are therefore probably fluctuations caused by inequalities in soil infestation, drainage, etc. A large number of selections from three such varieties, Livingston's Globe, Buckeye State, and Duke of York, were tested by the writer, but not one surpassed



BEHAVIOR OF VARIETIES OF TOMATOES GROWN ON WILT-INFECTED SOIL. II.

Rows 1, 3, and 5, Marvel; row 2, John Baer; row 4, Stone.

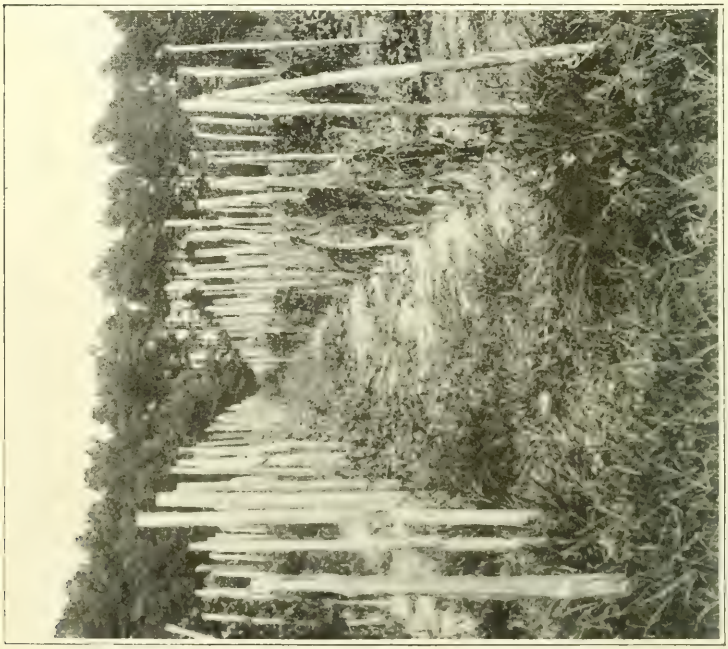
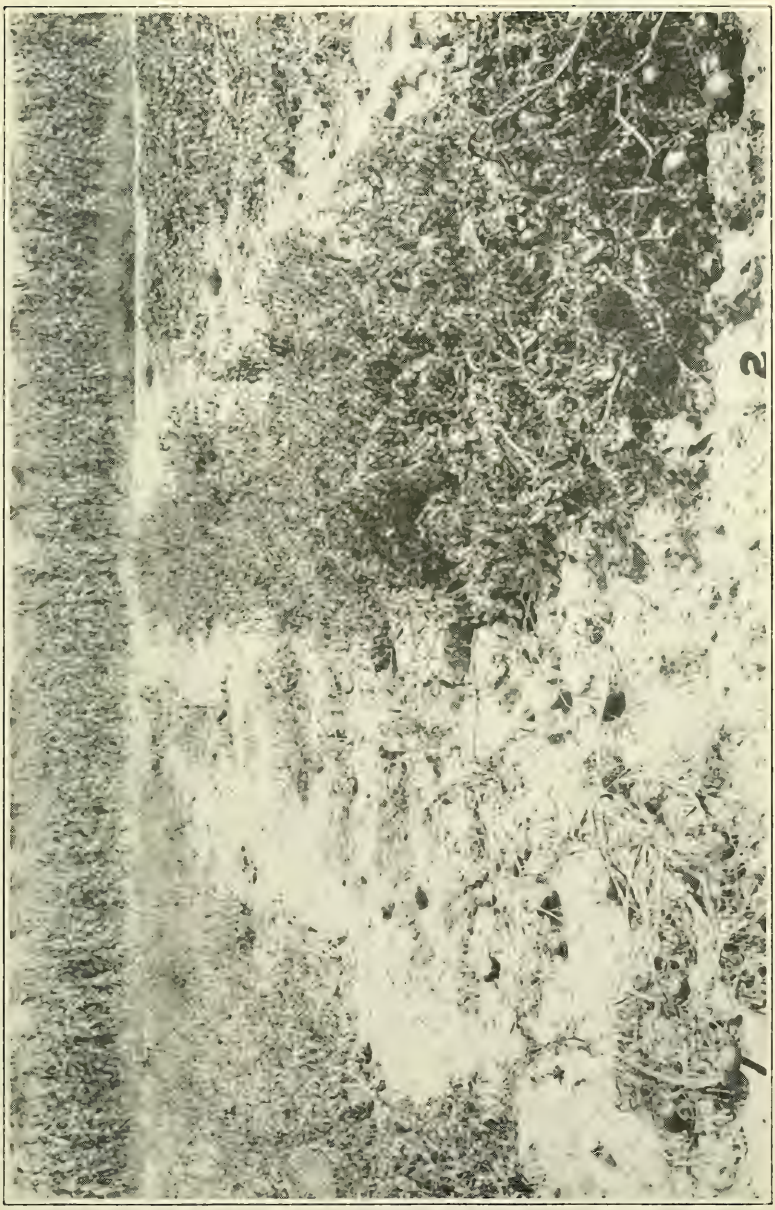


FIG. 1.—Nonresistant Brimmer tomato grown near Richmond, Va.

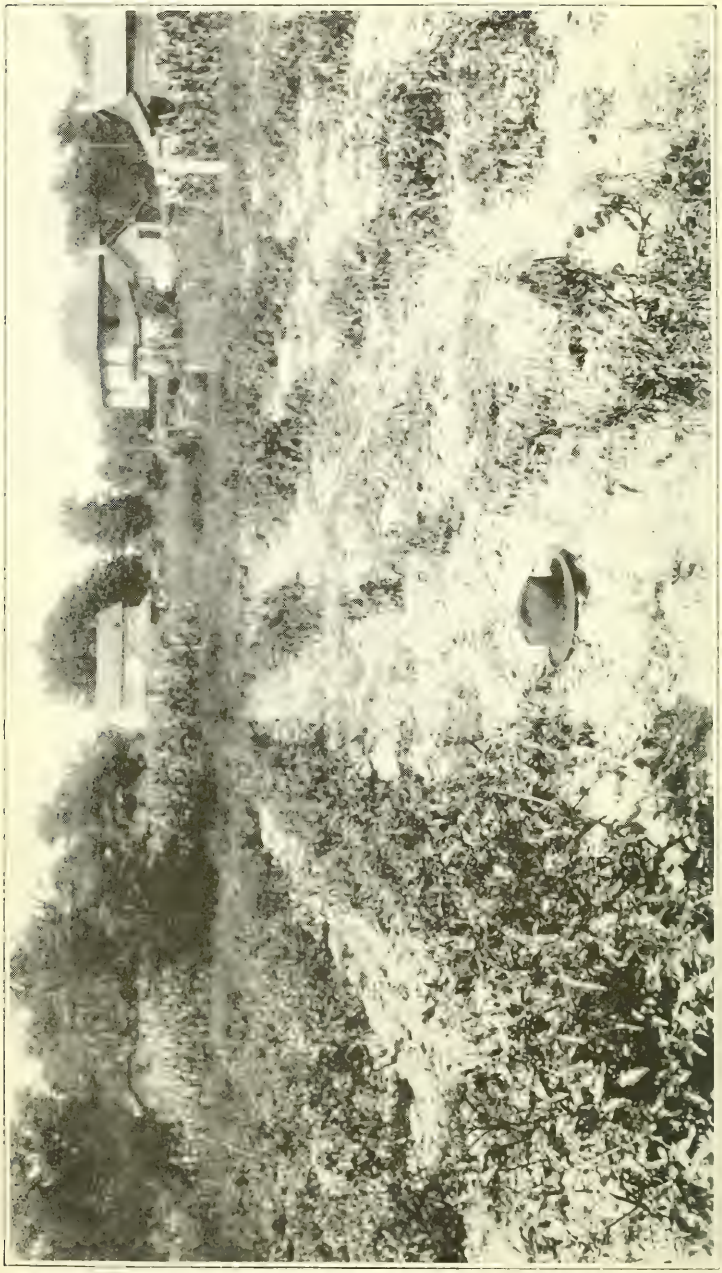
FIG. 2.—Wilt-resistant Norton tomatoes grown in the opposite ends of the rows of Brimmer shown in figure 1.

BEHAVIOR OF VARIETIES OF TOMATOES GROWN ON WILT-INFECTED SOIL. III.



BEHAVIOR OF VARIETIES OF TOMATOES GROWN ON WILT-INFECTED SOIL. IV.

Row 1, Greater Baltimore; row 2, Arlington (selected from Greater Baltimore).



BEHAVIOR OF VARIETIES OF TOMATOES GROWN ON WILT-INFECTED SOIL. V.

The row left of the center are of the Norton variety, grown at Brazil, Ind.; those at the right of the center are commercial varieties (one row of each)

its parent variety in degree of resistance transmitted. In another similar case, 30 apparently resistant plants of Earliana and 118 of Bonny Best, the only wilt-free plants found in two fields of 6 acres each, failed to transmit more than average resistance for their respective varieties.

Selections from varieties that transmit resistance to their individual plants somewhat diversely, such as the Stone, Greater Baltimore, and Merveille des Marchés, not infrequently excel their parents in the transmission of wilt resistance.

BEHAVIOR OF RESISTANT VARIETIES.

Although none of the varieties of wilt-resistant tomatoes developed by the writer are immune to wilt, they are highly resistant to it. In repeated tests on heavily wilt-infested soils they have maintained a high degree of resistance. A more important possession, however, is their high yield and the superior quality of their fruit when grown on wilt-infested soil. As they have been selected from the best commercial varieties, primarily for yield and quality of fruit and secondarily for wilt resistance, they possess the high yielding power of the parent varieties in addition to resistance and are therefore equal to them on wilt-free soil and far superior to them on wilt-infested soil. The behavior of two of these varieties is illustrated in Plates VI and VII. Plate VI, figure 1, shows the Brimmer, a very popular variety in the South, while figure 2 is the Norton. They were grown in opposite ends of the same rows near Richmond, Va. The Brimmer was absolutely destroyed by wilt, while the Norton produced an excellent crop of fruit. In Plate VII, row 1 is the Greater Baltimore and row 2 the Arlington, a selection from the Greater Baltimore. Although planted at the same time and given identical cultural conditions, the Greater Baltimore was completely destroyed, while the Arlington was apparently free from wilt and produced a good crop of fruit.

EFFECT OF CONTINUOUS SELECTION.

A tomato plant usually transmits to its immediate offspring as much wilt resistance as can be developed from it by subsequent selection. In a very small percentage of plants tested for wilt resistance by the progeny-row method, increased resistance has been obtained in the second selection, but no higher resistance has resulted from a continuation of this process. As crossing occasionally occurs in the tomato, the hybrid condition resulting from it may account for the exceptions noted.

The effect of continuous selection from two wilt-resistant varieties developed at Washington, D. C., and from one developed in Louisiana are shown in Table 2. The tests were made in rows of 16 plants

each on the wilt-infested breeding plats at the Arlington Experimental Farm. After one to three years of continuous selection the selected strains were planted beside the resistant varieties from which they were selected.

TABLE 2.—*Effect of continuous selection of varieties of tomatoes on the resistance to wilt.*

Variety and year.	Field.	Number of plants in the experiment.		Percentage of plants showing a trace of infection.	
		Variety under test.	Selections from same.	Variety under test.	Selections from same.
Norton:					
1917	3	15	48	33	63
1917	1	16	175	50	39
1918	1	48	32	52	63
1918	2	16	16	19	19
1919	2	16	112	69	66
Marvel:					
1918	1	16	64	19	8
1918	2	48	16	31	34
Louisiana Wilt-Resistant:					
1916	1	48	25	65	76

Continuous selection has apparently made no improvement in the wilt resistance of these strains. Whenever the real differences become small, however, as in the present case, they are obscured by fluctuations caused by environmental factors. Such a factor is soil moisture. On wet spots wilt is much worse than on better drained areas. Moreover, water is probably not the only variable environmental factor that affects the development of wilt. Until the methods of reducing these environmental effects are sufficiently refined to enable the breeder to distinguish real differences from fluctuations it will be impossible to determine whether or not continuous selection leads to further improvement. Under the present methods it does not seem to do so. The writer has found no difference in this respect between tomatoes, which are nearly always self-fertilized, and sugar beets,[4] which are normally cross-fertilized.

DURATION OF RESISTANCE.

Wilt resistance is apparently as permanent as other characters of the tomato. It fluctuates somewhat with changes in soil temperature, soil moisture, and other physiological factors, but on the average is less variable than tomato fruit characters. Its stability is shown by the fact that the varieties developed by the writer have maintained the same degree of resistance under both continued and discontinued selection and have remained relatively constant in all places tried. This is further supported by the fact that varieties

[4] Some recent investigations in sugar-beet breeding. *In* Bot. Gaz., v. 62, no. 6, p. 425–465, 51 figs. 1916.

developed by Edgerton and by Bain and Essary have shown approximately the same resistance at Washington as in Louisiana and Tennessee. The permanence of wilt resistance would therefore seem to depend on the prevention of crossing with susceptible varieties.

RESULTS OF FIELD TESTS.

Field tests[5] of the varieties of tomatoes described in this bulletin have been made on an extensive scale in Maryland, Delaware, Virginia, Georgia, and Alabama and on a smaller scale in 19 other States. In no case[6] have these varieties failed to maintain a high degree of resistance to wilt. Numerous reports from pathologists, horticulturists, canners, truckers, and growers of home gardens show that the yield and quality of fruit have usually been much better than from other varieties. On heavily wilt-infested soils the superiority of the resistant varieties has often been very great; in fact, in many fields in which it has been impossible to grow tomatoes for years on account of wilt these varieties have produced a heavy crop of fruit.

Wilt resistance in these tests has not usually been reported on a percentage basis by tomato growers, as they are not always able to distinguish wilt from blight or other diseases. Moreover, they are interested in general results more than in percentages, and they therefore usually report by means of such general statements as these:

They were beauties and splendid yielders. They surely had a fair chance and proved to be nonwilt. When one-half of our patch was dead, they were green and the ground lay full of nice tomatoes.

Up to date none of the plants of yours have shown any sign of wilt, whereas all other plants of tomatoes I had wilted badly, being entirely destroyed long ago.

Throughout the entire county the tomato crop was a complete failure except the ones that used the wilt-resistant seed.

They were all heavy bearers and none of them wilted.

Your tomatoes were grown in four different parts of a 10-acre field of Stone tomatoes. The fruit and quality were better than the Stone tomatoes.

The Norton gave at least double the yield of the Greater Baltimore.

If we could buy the kind of seed you sent us last spring in sufficient quantities to plant our entire crop, it would double our yield, even if the vines were slightly affected by the wilt.

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[5] Many of these tests were arranged with commercial tomato growers and growers of home gardens by plant pathologists, botanists, and horticulturists of the State agricultural experiment stations and by members of the Office of Extension Work South in the States Relations Service. Much credit should be given to these cooperators, especially to C. E. Temple, Thomas F. Manns, J. M. LeCato, F. D. Fromme, George L. Peltier, G. M. Armstrong, and Ola Powell, who have conducted extensive tests.

[6] One apparent exception to this statement was made by McClintock to the Plant-Disease Survey when he reported: "All so-called resistant strains which we were able to obtain were tested in badly infested soils in 1919 and none proved sufficiently resistant to grow and bear throughout the summer." As these results are so different from those reported by McClintock for Georgia the previous year and by others for several years and from several thousand reports received from various localities in Georgia and other States, the writer is of the opinion that wilt was not the sole cause of these unfavorable results.

The tomatoes you sent us gave fully twice as many fruits per acre as the others; besides, the fruits were of a much better quality.

I had a canning-club girl who planted one-tenth acre in disease-proof seed. She has canned 1,100 quarts of tomatoes, made 1 dozen bottles of catsup, and 3 gallons of green-tomato pickle from her patch. These are the only tomatoes that have been raised on this ground for years; all other plants would grow to be about a foot high, take the wilt, and die.

Although most of the reports received state the results in some such popular way as expressed in the foregoing paragraphs, a few report them in percentages of infected plants. Mr. Lewis Walker, county agent, Waycross, Ga., says:

I had one plat to run 100 per cent resistant and I feel that all the work would have averaged at least 95 per cent resistant. They were placed beside other seed and all wilted to about 60 per cent, leaving yours good.

Dr. G. A. Osner, formerly of the Indiana Agricultural Experiment Station, reported the data included in Table 3 on the test of the Norton variety.

TABLE 3.—*Comparative resistance to wilt of varieties of tomatoes at Lafayette and Brazil, Ind., in 1917.*

Variety.	Locality.	Number of plants.	Percentage of plants dead or badly diseased.
Norton	Lafayette	102	6.8
17 other varieties	do	627	67.0
Norton	Brazil	160	2.0
14 other varieties	do	1,045	55.0

The Norton was much more resistant than the other varieties and produced a better yield and quality of fruit. Although a small percentage of Norton plants was infected by wilt at the end of the season, this was not apparent in August when the writer visited these fields. A view of part of the field at Brazil is shown in Plate VIII. The rows at the left of the center are the Norton; those at the right are commercial varieties. The view shows only a few commercial varieties (one row of each) growing beside the Norton, but there were 14 commercial varieties in this field.

The percentages of wilt-free plants reported by Prof. D. C. Neal, plant pathologist of the Georgia State Board of Entomology, are grouped in Table 4. Included in this test were one of Edgerton's varieties, viz, Louisiana Hybrid (probably Louisiana Red or Louisiana Pink), Stone, and Livingston's Globe.

The resistant varieties, Louisiana Hybrid, Columbia, Marvel, Norton, and Arlington, were superior to Livingston's Globe, a somewhat resistant variety, and much superior to Stone, a typical susceptible variety. Although it is not stated whether the percentages

are based on real or apparent resistance, it is quite likely that they refer to apparent resistance.

TABLE 4.—*Comparative resistance to wilt of several varieties of tomatoes at Thomasville, Ga., in 1919.*

Variety.	Number of plants.	Percentage of wilt-free plants in August.	Variety.	Number of plants.	Percentage of wilt-free plants in August.
Louisiana Hybrid	57	96	Norton	55	90
Columbia	54	94	Livingston's Globe (check)	60	70
Marvel	58	94	Arlington	58	96
Stone (check)	60	46			

The percentages of wilted Norton plants reported for Georgia in 1917 by Mr. J. A. McClintock are summarized in Table 5. As not all of these fields were visited, it is quite likely that some of the injury attributed to wilt may have been due to blight or root-knot.

TABLE 5.—*Comparative resistance to wilt of the Norton and several commercial varieties of tomatoes in Georgia in 1918.*

County.	Number of experimenters.	Size of planting.	Wilt noted.	
			In Norton.	In checks.
			Per cent.	*Per cent.*
Ware	8	One-tenth acre	5	10 to 90
Colquitt	20	do	2 to 5	75 to 100
Thomas			5	100
Glynn	12	One-tenth acre	35	50
Chatham	35	Half acre or less	[a] 20	40 to 75
Dodge	14	One-tenth acre	2	50 to 75
Toombs	10	do	0	25 to 50
Bibb	24	do	Small.	([b])
Walton	12	do	3	85
Coffee	10	One-twentieth acre	3	10 to 30
Brooks	4	About 100 plants per person	0	20

[a] In one instance. [b] More than Norton.

The percentages in Table 5, which probably refer to apparent resistance, agree fairly well with those in Table 4. In some instances, as in Glynn County, it is quite possible that wilt was not always distinguished from blight or root-knot. For Chatham County only one result is reported, and it is a percentage which is very likely much higher than the average for the 35 tests. But even as the results of these tests are reported, they show that the Norton is much more resistant to wilt than the commercial varieties planted beside it.

The results reported by Edgerton for Louisiana in 1920 are summarized in Table 6. They include data on Edgerton's wilt-resistant varieties, Louisiana Red and Louisiana Pink, and also on several commercial varieties. The percentages are arranged in two columns:

(1) Those of plants apparently infected, determined by visual inspection only, and (2) those of plants actually infected, determined by cutting the stems and noting the appearance of the tissues.

TABLE 6.—*Comparative resistance to wilt of several varieties of tomatoes in Louisiana in 1920.*

Variety.	Plants infected.		Variety.	Plants infected.	
	June 25, apparent infection.	July 11, actual infection.		June 25, apparent infection.	July 11, actual infection.
	Per cent.	*Per cent.*		*Per cent.*	*Per cent.*
Marvel	6.6	55.7	Earliana	47.6	87.6
Louisiana Red	6.2	62.2	Manyfold	24.5	90.7
Louisiana Pink	6.3	69.3	Early Jewel	58.4	92.7
Norton	5.0	70.0	Stone	78.3	96.1
Columbia	15.0	75.4	June Pink	60.1	96.6
Arlington	13.2	77.7	Bonny Best	80.6	97.2
Livingston's Globe	1.2	77.9			

There is considerable difference between these varieties in percentage of plants apparently infected, but not so much in percentage of plants actually infected. As apparent infection is somewhat closely related to degree of infection, the percentages recorded in the first figure column show the superior resistance of varieties developed for resistance to wilt. However, the resistance of Livingston's Globe was much higher in these tests than the writer has personally observed. In a test of 87 strains of the Globe variety at the Arlington Experimental Farm in 1920 the percentage of apparently infected plants was much higher than for the Marvel, Norton, Arlington, Columbia, or Louisiana Red. The Globe must therefore fluctuate considerably in its resistance to wilt.

The report in Table 7 by Mr. U. G. Swingle, of Columbus, Ohio, gives a fairly good comparison of the behavior of the Marvel variety in wilt-infested soil in a greenhouse as compared with commercial varieties. The Arlington, Columbia, and Norton varieties were used in this test, but only on a small scale, as they are rather large, heavy, and late for forcing.

TABLE 7.—*Comparisons of wilt-resistant and nonresistant varieties of tomatoes in a greenhouse at Columbus, Ohio, in 1919.*[a]

Variety.	Number of plants.	Average yield per plant.	Average returns per plant.	Yield per acre.
		Pounds.		*Tons.*
Resistant varieties, mostly Marvel	1,650	4.76	$1.02	22
Nonresistant varieties, mostly Bonny Best	5,160	3.23	.70	15

[a] Swingle, U. G. Successful greenhouse tomato crop. *In* Market Growers' Jour., v. 25, no. 11, p. 7. 1919.

Table 7 shows the effect of resistance on yield. Because of its wilt resistance, the Marvel was able to produce a much better crop than the Bonny Best. There is probably no more productive tomato than the Bonny Best when grown in an environment free from disease, but like most other tomato varieties it is susceptible to wilt and can not produce a heavy crop on wilt-infested soil; in fact, when the soil is heavily infested by wilt it produces very little fruit. The resistant varieties are so lightly attacked by wilt that they are hardly affected by it.

In regard to their wilt resistance, Swingle says:

> There was a wonderful difference in vitality between the resistant and non-resistant varieties. All the latter were practically dead before the end of the season and consequently did not mature all their fruit. The resistant varieties were all still green on July 25 when pulled up.

In some rows the resistant varieties were planted at the ends; in others in the middle. Although the resistant varieties were still green when pulled up, the others were so dry they could be lighted with a match.

ORIGIN AND DESCRIPTION OF WILT-RESISTANT VARIETIES.

The Marvel is a selection from Merveille des Marchés (Marvel of the Market), a French variety sold by Vilmorin-Andrieux & Co., Paris, France. Before it was named it was distributed for trial as F 59. The Marvel and F 59 are therefore the same variety.

Under favorable conditions the Marvel produces a heavy crop of medium-early smooth red fruit, similar in size, shape, and smoothness to the fruit shown in Plate IX, figure 1. It usually sets a great many fruits and continues to bear heavily long after most early varieties are dead.

It is highly resistant to tomato wilt and possesses a little resistance to tomato leaf-spot (*Septoria lycopersici*).

It is an excellent variety for forcing, for medium-early trucking, and for home gardening. Its wonderful vitality of vine, its relative freedom from diseases, and its superior fruit for use in the fresh state make it an excellent tomato for all-round use.

Variety very productive, medium early, long bearing, highly resistant to tomato wilt (*Fusarium lycopersici*), somewhat resistant to leaf-spot (*Septoria lycopersici*) and to leaf-mold (*Cladosporium fulvum*).

Plant medium large, erect, vigorous; branches many, long, medium stout; internodes long.

Foliage type, standard;[7] leaves large, deeply divided, smooth, dark green, shading the fruit.

Flowers large; fruit cluster small, many, scattered.

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[7] In making comparisons three types of foliage were used, viz, standard, potato leaf, and Dwarf Champion.

Fruit medium large, oblate, bright red, with occasional shallow cracks either encircling or radiating from the stem; stem-end cavity shallow, smooth; blossom-end basin small; stylar scar small, circular; skin thin; vertical section medium long, oval; cross section round, smooth; walls thick, firm, juicy, evenly colored; cells many, small, irregular, well filled; seeds fairly numerous, small; pulp medium thick; core not defined; flavor sprightly acid.

The Arlington[8] and Columbia varieties are selections from the Greater Baltimore. As they are similar in fruit characters, the illustration for the Arlington (Pl. IX, fig. 2) will serve for both varieties.

Like their parent variety, the Arlington and Columbia produce a heavy crop of large, smooth, deep-red fruit, which ripens uniformly; in fact, it is practically free from green tissue around the stem by the time the blossom end is ripe, but it ripens so fast that it can not be held long. Although they are similar in many respects, the Arlington produces a little larger vine than the Columbia and seems to possess a little more resistance to wilt. There is very little difference, however, in their yield.

They are medium-late tomatoes of the canning type and should be tried wherever the Greater Baltimore is used, as they are adapted to the same environmental conditions and produce the same quality of canned fruit.

Variety very productive, late, highly resistant to tomato wilt (*Fusarium lycopersici*), somewhat resistant to leaf-spot (*Septoria lycopersici*).

Plant large, erect, vigorous; branches many, long, stout, internodes long.

Foliage type, standard; leaves large, deeply divided, smooth, yellowish green, shading the fruit.

Flowers large; fruit clusters small, many, scattered.

Fruit large, oblate, dark red, very seldom cracked; stem-end cavity medium deep, ribbed; blossom-end basin small, fairly deep; stylar scar small, irregular; skin medium thick; vertical section short, oval; cross section round, smooth except near stem; walls thick, firm, juicy, evenly colored; cells many, small, irregular, well filled; seeds fairly numerous, medium large; pulp medium thick; core not defined; flavor pleasantly acid.

The Norton is a selection from the Stone, which has been distributed both as F 20 and as Norton by the Office of Cotton, Truck, and Forage Crop Disease Investigations and as Wilt-Resistant Stone by Prof. C. E. Temple in Maryland. The original fruit from which it descended was selected by Mr. J. B. S. Norton, of the University of Maryland, and with several other seed samples was given to the writer for trial in the spring of 1915. The fruit produced by this selection was exceptionally good for the conditions under which it was grown. The plants, though with one exception badly infected, showed some resistance to wilt. One plant contained only a mere trace of infec-

[8] As some of the seed of this variety which was distributed in 1919 and 1920 was found to be impure, having given several different off types of tomatoes, a result, it is believed, of accidental crossing in the seed-production fields, the seed has been withdrawn until it can be fully purified.

FIG. 2.—Arlington.

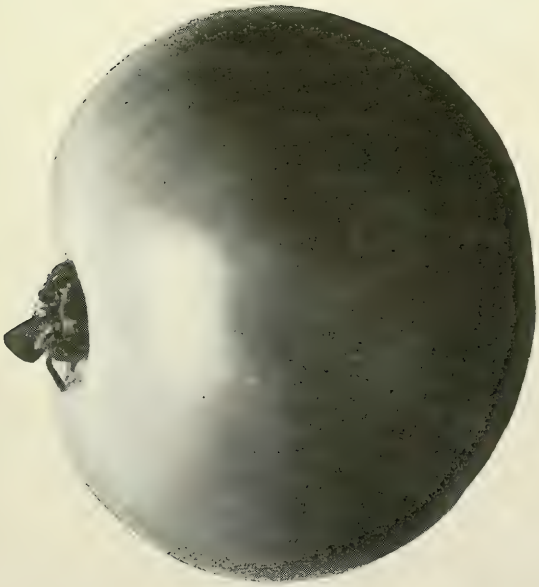

FIG. 1.—Marvel.

NEW VARIETIES OF WILT-RESISTANT TOMATOES. I.

About average natural size.

Norton.

NEW VARIETIES OF WILT-RESISTANT TOMATOES. II.

About average natural size.

tion and produced a heavy crop of fruit. Cuttings were made from this superior plant and transferred to the greenhouse. By repeatedly making cuttings during the winter from this greenhouse material enough seed was obtained by spring to make an acre field test. The results were so good that the entire crop was saved for seed and used for making extensive field trials in 1917. This new strain was equal to the original strain in quality and quantity of fruit and much superior to it in wilt resistance. This is one of the cases in which a second selection gave further improvement, the other cases being selections from Merveille des Marchés.

The Norton produces a heavy yield of large, smooth, solid red fruit (Pl. X), which ripens slowly and therefore ships well. It is similar to the Stone in time of maturity, but usually produces heavier yields and more solid fruit. It is highly resistant to tomato wilt (*Fusarium lycopersici*) and possesses a little resistance to tomato leaf-spot (*Septoria lycopersici*). It has frequently been commended by growers for resistance to drought, but its apparent drought resistance is probably due largely to its resistance to wilt.

It is an excellent tomato for canning, for home gardening, and for late trucking, as it not only produces an excellent crop of fruit, but begins to ripen about midseason and continues to bear heavily until killed by frost.

Variety, very productive, late, highly resistant to tomato wilt (*Fusarium lycopersici*) and somewhat resistant to leaf-spot (*Septoria lycopersici*).

Plant large, erect, vigorous; branches many, long, stout; internodes long.

Foliage type, standard; leaves large, smooth, dark green, deeply divided, shading the fruit.

Flowers large; fruit clusters small, many, scattered.

Fruit large, smooth, oblate, bright red, very solid, comparatively free from cracks; stem-end cavity shallow, smooth to smooth ribbed; blossom-end basin medium small, shallow; stylar scar small, circular to linear; skin thin; vertical section medium long, oval; cross section round to oval, smooth; walls thick, firm, juicy, evenly colored; cells many, small, irregular, well filled; seeds few, medium large; pulp thick; core not defined; flavor pleasantly acid.

SUMMARY.

Tomato wilt (*Fusarium lycopersici*) causes in the United States an annual loss of more than 115,000 tons of tomatoes. By the use of wilt-resistant varieties this loss can be overcome at the mere expense of handling the extra crop.

Three varieties of tomatoes developed by the writer and one developed by Mr. J. B. S. Norton and the writer produce heavy crops of excellent fruit on land so heavily infected by wilt that ordinary tomatoes can not be grown on it. They are selections from the Greater Baltimore, Stone, and Merveille des Marchés (Marvel of the Market), three of the best commercial varieties of tomatoes grown, and possess in addition to wilt resistance all the good qualities of their parent varieties. Moreover, extensive field tests have shown

them to be well adapted to all parts of the United States in which tomato wilt is present.

Very few commercial varieties possess appreciable resistance to wilt. The Duke of York and the Buckeye State, apparently one variety under two names, are highly resistant, but they produce poor fruit. Livingston's Globe is somewhat resistant, but its purple fruit is objectionable to canners and is not in universal favor in other markets. Moreover, it is very susceptible to nail-head rust, a destructive disease prevalent in the South, where this variety is most commonly grown.

Varieties that normally produce a heavy crop of excellent fruit and vary considerably in the degree of wilt resistance possessed by their individual plants afford the best material for the development of superior wilt-resistant varieties by selection. Although such varieties may be very susceptible to wilt, they are nevertheless valuable if they produce occasional resistant plants, as such plants are usually much better material than selections from more resistant varieties that produce a poorer crop of fruit. Most varieties transmit approximately the same degree of wilt resistance to all their plants and consequently offer little opportunity for improvement by selection.

Tomato plants selected for wilt resistance usually transmit to their immediate offspring as much resistance as can be developed from them by subsequent selection. In a few instances increased resistance has been obtained in the second selection, but not in later selections. This may be due either to a limited response of the material to selection or to an obscuration of real differences by fluctuations.

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L. O. HOWARD, Chief

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BIONOMICS OF THE CHINCH BUG.

By PHILIP LUGINBILL, *Entomological Assistant, Cereal and Forage Insect Investigations.*

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INTRODUCTION.

During several years past the biology of the chinch bug (*Blissus leucopterus* Say) has been studied in South Carolina with a view to the control of the insect in that region. It is a pest of considerable importance, especially in some of the northern counties of the State. Many planters in this region will plant no grain, giving as a reason that attempts to grow grain result in producing chinch bugs, and as a consequence they are unable to make a corn crop. Coincident with the conduct of field investigations, some time was devoted to a study of the insect in the laboratory at Columbia, and although this work is not complete, certain novel facts regarding the life history of the pest have been learned which make it advisable to publish immediately the information thus obtained. Wherever the chinch bug has been treated in the literature, it has always been represented as passing through five instars in its development. By means of the experiments conducted at Columbia, S. C., it has been shown that in this locality the insect has six instars, instead of five, exclusive of the egg stage, viz, five immature stages, the sixth being the adult stage. The figures of the stages of this insect given by C. V. Riley, which have been used over and over again in various bulletins and other works on this subject, therefore are incorrect, at least in so far as South Carolina is concerned. Specimens of the different stages were preserved at Columbia, and from these drawings have been made by

Miss E. H. Hart, to whom much credit is due. A dipterous parasite of the adult insect has also been reared for the first time, as described below.

SEASONAL HISTORY IN SOUTH CAROLINA.

NUMBER OF GENERATIONS.

There are two generations of the chinch bug annually in the South, the same as in the North. The adults begin to mate shortly after they emerge from hibernation quarters, this emergence occurring during the latter part of April, as mentioned elsewhere in this paper. A few pairs in copula, however, have been collected prior to this date. General copulation does not occur until after the spring migration, or after the adults have reached their feeding ground; it usually takes place during the first week in May, although the time varies somewhat. Eggs are deposited shortly after, and by the latter part of May nymphs appear. By the end of the first week in June the majority of the old adults are dead and by the middle of the same month new adults begin to appear, although not attaining their maximum abundance until some time in July. Part of June, July, and part of August are covered by the second generation, which may be called the summer generation. The adults from this generation appear in September and October, and some probably in early November, and go into hibernation for the winter. The two generations overlap to such an extent that during the summer months all stages of the insect may be found in the fields at once.

HIBERNATION.

In the South this insect passes the winter in the adult stage among old, dead cornstalks, especially under their leaf sheaths and in their husks. There is no doubt that many individuals also hibernate among dead grass, along terraces and borders of fields. They are not found in any great numbers in any one place during this season of the year, but are fairly well scattered, so much so that it is a difficult matter to find any quantity of them at any one time. The bugs apparently feed but little during winter but remain hidden until the warm spring sun arouses them to activity and they prepare for their spring migration.

DISSEMINATION.

This insect migrates from its winter quarters to grain fields principally by flight. The adults of the hibernating generation apparently consist exclusively of winged forms and are fully capable of spreading into fields of forage and grain. Thus far no short-winged individuals have been found among the spring migrants. The exact time when migration takes place in spring has not been definitely

determined, but apparently it is during the month of April. Migration is governed largely by seasonal conditions. The phenomenon of migration in this insect in spring on such an extended scale is a topic for general conversation among the planters in regions subject to infestation. The planters state that during migration the bugs fill the air like swarms of bees and are even known to enter dwellings at night. To a lesser extent the adults spread on foot to grain fields from their winter quarters, especially when such fields are not far removed from where the bugs have hibernated. It is not an uncommon practice in the South to sow grain, especially winter oats, on corn stubble land, and in such cases the adults find their food without having to search for it. There does not appear to be any definite summer migration. This may be due partly to the fact that a large number of the individuals of the summer generation are short-winged forms, unable to fly, and hence are compelled to seek fresh fields by crawling to them.

BEHAVIOR.

Adult chinch bugs often feign death when disturbed, especially when they happen to be lying on their backs. When it is least expected, however, they will right themselves quickly and scamper away to seek concealment under the nearest shelter, and are then difficult to capture. They are exceedingly quick on their feet, and when a vial, in which they are held captive, is opened, are often able to regain their freedom before the observer realizes what has happened. When adults are captured in the field they frequently escape by crawling through the little spaces between one's fingers and quickly drop to the ground. The nymphs of all stages are quite as active as the adults and often escape from captivity in a similar manner. Activity, of course, depends upon prevailing temperatures. Early in the morning the adults and nymphs are often quite sluggish and are easily taken, but by the middle of the day they become exceedingly active.

This insect is a sociable creature, both in its nymphal and adult stages, and when a number of individuals are placed in the same cage they will be found, later on, feeding in a little group. When disturbed they scamper in all directions, to reassemble when danger has passed. Upon removal of the lid from a tin ointment box used as an incubation cage the nymphs that had hatched were often found huddled closely together in a little group along the edge on the underside of the lid, these nymphs being very small when newly emerged.

MATING.

Mating takes place repeatedly among the individuals of this species, and may occur at intervals of from 5 to 8 days. The adults remain in copula for some time, occasionally for 12 hours or more,

and during this time are easily captured. During copulation the female alone remains active, traveling about frequently, and dragging the male helplessly after her. There is little doubt that there are both polyandry and polygamy among the adults of the chinch bug, since they mate an indefinite number of times.

LIFE HISTORY OF THE CHINCH BUG.

OVIPOSITION.

Under field conditions eggs are placed by the female near or on the plants upon which the insect feeds. Eggs may be found in the soil near the roots, at the base of the plants, but more often occur in the leaf sheath, which appears to be the preferred place.

In the laboratory bacteriological test tubes, of standard size, stoppered with absorbent cotton and supplied with parts of corn plants, were found to be the most successful type of egg cage. The corn plants used as hosts were about 6 inches high, with their foliage and the outer roots cut off before introduction into the cage. Sometimes parts of larger cornstalks were used when young corn was not available. In cages where young corn was supplied the eggs were laid on all parts of the plant, but most frequently were placed under the upper epidermal layer of the leaf sheath. This appears to be their favorite location, although many eggs were placed in the cotton stopper of the vial. Where parts of cornstalks were used, the eggs were often found pushed into the pith, on either end, to their entire depth, sometimes two and three together. In the leaf sheaths they are often found in quantities, side by side. In one instance 16 eggs were found placed in this manner in a neat, compact row. With a little care the whole row was lifted out without any of the eggs becoming detached. It was not often that eggs were placed loosely in the vials. It seems that the female desires to conceal her eggs from possible predacious enemies.

Eggs in cages were deposited during all hours of the day. It is possible that some may be deposited during the night, but this is doubtful. In the field it is quite likely that very few eggs are deposited during early morning hours, the temperature at that time of the day being lower and damp, which causes the adults to become numb and therefore sluggish.

NUMBER OF EGGS DEPOSITED BY A SINGLE INDIVIDUAL.

Considerable variation has been noted in the number of eggs deposited by an individual female of this species. Such variation undoubtedly is governed to some extent by seasonal weather conditions. There is no doubt, however, that some females are by nature more fecund than others.

Females and males, taken in copula in the field very early in spring, were placed in test tubes and counts made of the number of eggs laid. Data relating to four of these cages are given in Table I. The largest number of eggs deposited in any one of the four cages was 119, in cage 20–51. The smallest number, 51, was obtained in cage 20–53. The average number deposited by one female, based on the four individuals, is 85.25 eggs. Oviposition extended over a period of 56 egg-laying days in cage 20–50, and only 41 days in cage 20–51, although more eggs were deposited in the former cage than in the latter.

Although the individuals were collected from the field, there does not seem to be much doubt that the females had begun to oviposit before they were captured, since they were taken at the time of their migration and shortly afterwards, and at the time when they were copulating in great numbers.

TABLE 1.—*Records of daily and total egg production of four individuals of Blissus leucopterus, Columbia, S. C., 1920.*

Cage No. 20–50.		Cage No. 20–51.		Cage No. 20–53.		Cage No. 20–55.	
Date of oviposition.	Number of eggs.	Date of oviposition.	Number of eggs.	Date of oviposition.	Number of eggs.	Date of oviposition.	Number of eggs.
May 11	1	May 8	1	May 9	.....	May 9	.....
May 12–26	.....	May 9–25	.....	May 10	12	May 10	6
May 27	2	May 26	6	May 11	.....	May 11	.....
May 28–31	.....	May 27–28	.....	May 12	3	May 12	.....
June 1	2	May 29	2	May 13	1	May 13	2
June 2	1	May 30–31	9	May 14	2	May 14–24	.....
June 3	2	June 1	2	May 15–20	.....	May 25	6
June 4	3	June 2	5	May 21	3	May 26	.....
June 5	1	June 3	10	May 22–24	10	May 27	3
June 6–7	3	June 4	4	May 25	4	May 28	6
June 8–9	2	June 5	5	May 26	2	May 29	10
June 10	4	June 6–7	14	May 27	6	May 30–31	6
June 11	6	June 8–9	10	May 28	3	June 1	4
June 12	.....	June 10	2	May 29	5	June 2	13
June 13–14	14	June 11	5			June 3	6
June 15	2	June 12	3			June 4	10
June 16	7	June 13–14	23			June 5—Female dead; dissected.	3
June 17–18	10	June 15	11				
June 19	3	June 16	5				
June 20–21	12	June 17–18	2				
June 22–23	7						
June 24	2						
June 25–26	3						
June 27–29	.....						
June 30	1						
July 1–6	7						
Total	95	Total	119	Total	51	Total	75

LENGTH OF THE EGG STAGE.

The length of the incubation period is governed primarily by prevailing temperature. During early spring it may be slightly more than a month and during midsummer a trifle more than a week. In the laboratory at Columbia, S. C., a record on the incubation period

of 664 eggs was obtained during the spring and summer of 1919 and 1920. These data are given in Table 2. The longest period obtained for the egg stage was 31 days. This egg hatched on June 8 from a lot of 103 deposited on May 8. The shortest egg period was 9 days, during July. There is a gradual decrease in the length of the egg stage from early May to July, and during August it again increases.

Not all of the eggs of one day's deposition hatch on the same day, although the reason for this is not definitely known. It may be that some eggs are not sufficiently supplied with moisture, or with the same amount that the others receive, and consequently develop more slowly. There may be a difference of nine days in the time of hatching in the same lot of eggs, as will be noted in Table 2 under entry of May 8. The greater number of this lot of 103 eggs, however, hatched within 3 days after hatching began. The first eggs in this lot hatched on May 31, the last on June 8. There is a greater range in the time of hatching in a single lot of eggs in the early spring months than in the summer months. In the latter period a lot of eggs laid on the same day generally hatch within at most 3 days after hatching has begun, and quite often all of them hatch on the same day.

The weighted average for the egg period of the 664 eggs recorded in Table 2 is 21.96+ days.

The type of cage used for observation purposes on the incubation period consisted of a very small tin ointment box with a plaster of paris bottom. The porous qualities of this substance permitted introduction of just the right amount of moisture. No great difficulty was experienced with fungus, which often develops in closed boxes where moisture is present, especially when used continuously for as long a time as in these experiments. This type of egg cage has been found exceedingly satisfactory for making observations on the egg stages of various insects, especially those which lay their eggs in the soil or other damp places, and therefore have to be kept fairly moist if good results are to be obtained. It was devised in connection with investigations of the southern corn rootworm (*Diabrotica 12-punctata* Oliv.).

TABLE 2.—*Length of incubation period of eggs of Blissus leucopterus, Columbia, S. C., 1919–20.*

Eggs deposited.		Eggs hatched.		Length of egg stage.	Eggs deposited.		Eggs hatched.		Length of egg stage.
Date.	Number.	Date.	Number.		Date.	Number.	Date.	Number.	
				Days.					*Days.*
May 4	3	May 29	3	25	June 1		June 17	8	16
May 6	6	May 31	1	25			June 18	1	17
		June 1	3	26	June 2	33	June 17	14	15
		June 2	2	27			June 18	12	16
May 8	103	May 31	12	23			June 19	2	17
		June 1	43	24			June 20	2	18
		June 2	40	25	June 3	32	June 16	1	13
		June 3	2	26			June 17	3	14
		June 4	1	27			June 18	8	15
		June 5	2	28			June 19	16	16
		June 6	2	29			June 20	1	17
		June 7	.....	.....			June 21	1	18
		June 8	1	31			June 22	2	19
May 9	9	June 2	6	24	June 4	17	June 18	4	14
		June 3	3	25			June 19	7	15
May 10	37	June 2	19	23			June 20	5	16
		June 3	14	24			June 21	.....	.....
		June 4	2	25			June 22	1	18
		June 6	.....	.....	June 5	12	June 19	1	14
		June 6	2	26			June 20	.....	.....
May 11	21	June 2	3	22			June 21	10	16
		June 3	11	23			June 22	.....	.....
		June 4	5	24			June 23	1	18
		June 5	.....	.....	June 10	6	June 22	1	12
		June 6	2	26			June 23	4	13
May 12	48	June 3	4	22			June 24	1	14
		June 4	28	23	June 11	10	June 23	2	12
		June 5	11	24			June 24	5	13
		June 6	5	25			June 25	3	14
May 13	39	June 3	1	21	June 12	9	June 24	3	12
		June 4	8	22			June 28	6	16
		June 5	12	23	June 15	11	June 28	2	13
		June 6	18	24			June 29	7	14
May 17	66	June 6	14	20			July 1	2	16
		June 7	39	21	June 19	3	July 3	3	14
		June 8	13	22	June 23	7	July 6	7	13
May 18	2	June 9	1	22	June 26	1	July 9	1	13
		June 10	1	23	June 27	46	July 10	44	13
May 19	12	June 7	12	19			July 12	2	15
May 21	3	June 12	3	22	June 28	5	July 11	2	13
May 22	2	June 12	2	21			July 12	3	14
May 25	58	June 14	18	20	July 1	1	July 12	1	11
		June 15	39	21	July 7	14	July 16	1	9
		June 16	1	22			July 17	2	10
May 26	22	June 14	6	19			July 18	11	11
		June 15	16	20	July 8	6	July 20	6	12
May 27	27	June 14	1	18	July 11	12	July 23	12	12
		June 15	23	19	July 12	14	July 25	13	13
		June 16	3	20			July 26	1	14
May 28	18	June 15	14	18	July 24	2	Aug. 4	2	11
		June 16	4	19	July 26	5	Aug. 8	5	13
May 29	23	June 15	1	17	July 27	2	Aug. 5	2	9
		June 16	22	18	Aug. 21	6	Sept. 5	6	15
June 1	11	June 16	2	15					

Total number of eggs, 664. Weighted average for the egg period, 21.96 + days.

FERTILITY OF THE EGGS.

Not all of the eggs laid by the chinch bug are fertile. Fertility may depend upon the number of times the female has mated or upon whether or not the female has recently mated. The fact that the female lays infertile eggs at times may explain the necessity for frequent copulation, for should she mate only once or the mating interval be too great, more of the eggs might be infertile. This, however, is somewhat conjectural and further observations on this point are necessary. In one instance 40 eggs out of a total of 503, or about 8 per cent, were infertile. In another case 5 eggs out of

a total of 56, or about 9 per cent, were infertile. In both instances males were with the females at all times.

NUMBER AND LENGTH OF INSTARS AND TOTAL LENGTH OF THE IMMATURE PERIOD.

According to experiments conducted at the laboratory at Columbia, S. C., in 1919, and again in 1920, the nymphs of this species molt five times during their development from egg to adult, the same number of times as do the nymphs of the squash bug (*Anasa tristis* De G.) and the harlequin cabbage bug (*Murgantia histrionica* Hahn). These species, although belonging to different families from the chinch bug, differ from this insect mainly in taxonomic characters rather than in their bionomics. There are indications that occasionally a nymph may molt only four times, as originally supposed, and very rarely six times. This, however, is the exception rather than the rule, and such variation is known to occur among larvæ of various species of lepidopterous insects.

TABLE 3.—*Number and length of instars and total length of immature period of Blissus leucopterus, Columbia, S. C., 1919–20.*

Cage No.	Nymph emerged.	Date of first molt.	Length of first instar.	Date of second molt.	Length of second instar.
			Days.		*Days.*
[1] 19-450	July 11	July 27	16	Aug. 2	6
19-454	July 11	July 27	16	July 31	4
19-459	July 16	July 27	11	July 31	4
19-462	July 9	July 18	9	July 24	6
19-463	July 10	July 19	9	July 26	7
19-466	July 10	July 27	17	July 31	4
19-468	July 10	July 20	10	July 27	7
19-473	July 16	July 27	11	Aug. 2	6
19-476	July 17	July 30	13	Aug. 4	5
19-478	July 17	July 27	10	July 31	4
19-528	July 26	Aug. 1	6	Aug. 10	9
[2] 20-700	June 11	June 29	18	July 5	6
20-736	June 15	June 29	14	July 5	6
20-747	June 15	June 29	14	July 5	6
20-748	June 15	June 29	14	July 5	6
20-751	June 12	June 28	16	July 5	7
	Average		12.75		5.75

Cage No.	Nymph emerged.	Date of third molt.	Length of third instar.	Date of fourth molt.	Length of fourth instar.	Date of fifth molt (adult).	Length of fifth instar.	Total length of immature period.
			Days.		*Days.*		*Days.*	*Days.*
[1] 19-450	July 11	Aug. 10	8	Sept. 5	26	Oct. 4	29	85
19-454	July 11	Aug. 9	9	Aug. 15	6	Sept. 5	21	56
19-459	July 16	Aug. 9	9	Aug. 19	10	Sept. 17	29	63
19-462	July 9	Aug. 2	9	Aug. 13	11	Sept. 8	26	61
19-463	July 10	Aug. 5	10	Aug. 15	10	Aug. 31	16	52
19-466	July 10	Aug. 8	8	Aug. 21	13	Sept. 20	30	72
19-468	July 10	Aug. 4	8	Aug. 21	17	Oct. 9	49	91
19-473	July 16	Aug. 9	7	Aug. 19	10	Sept. 5	17	51
19-476	July 17	Aug. 7	3	Aug. 29	22	Oct. 4	36	78
19-478	July 17	Aug. 7	7	Aug. 15	8	Sept. 16	32	61
19-528	July 26	Sept. 10	31	Oct. 1	21	Oct. 28	27	94
[2] 20-700	June 11	July 12	7	July 20	8	Aug. 3	14	53
20-736	June 15	July 17	12	Aug. 8	22	Aug. 29	21	75
20-747	June 15	July 10	5	July 26	16	Aug. 5	10	51
20-748	June 15	July 9	4	July 19	10	Aug. 11	23	57
20-751	June 12	July 12	7	July 29	17	Aug. 14	16	63
	Average		9		14.12+		24.56+	66.43

[1] 19 refers to the year 1919.

[2] 20 refers to the year 1920.

The data obtained in connection with the experiments on the number and length of instars of 16 individuals have been summarized in Table 3. In another series of approximately equal number, under observation for about the same period as were those of 1919 given in Table 3, four molts only were observed and the nymphs were then in their penultimate stage. The length of the period of the first instar, according to Table 3, varies from a minimum of 6 to a maximum of 18 days, the second varies from 4 to 9 days, the third from 3 to 31 days, the fourth from 6 to 26 days, and the fifth from 10 to 26 days. Taking the averages obtained in the series, the period of the second instar is the shortest, the third somewhat longer than the second, the fourth slightly longer than the first, and the fifth much the longest of all. The greatest number of days required for any one of the individuals in the series to reach maturity was 94, and the smallest number 51. The general average for the total length of the immature period in the series is 66.43 days.

It is not unlikely that the length of the instars and the length of the immature period were somewhat extended, because the nymphs were kept under somewhat unnatural conditions. In this study of number and length of instars in this species small shell vials (30 mm. in length) were found the most convenient and satisfactory. These were stoppered with absorbent cotton and the cotton was moistened as often as necessary when observations were made. Small bits of cornstalks were supplied as food for the nymphs. It was necessary to be very cautious to prevent an oversupply of water from gathering on the sides of the vials. When droplets gather the nymphs, in crawling along the sides, are overcome by the water and become helpless, and if not assisted to a drier place and the vial dried out will die in a short time.

ECDYSIS.

A short time before the nymph casts its skin it becomes much swollen, especially in the abdominal region. The abdomen is then much wider than the thorax, particularly in the region of the fourth and fifth segments. Before this it is about the same width as the thorax or a little wider. The period during which the nymph has this swollen appearance will be called the molting period, and preparations are then being made by the nymph to cast off its outer cuticular layer. This period corresponds precisely to that in lepidopterous larvæ known as the molting period, during which the larvæ become sluggish, feed little or none, and prepare to shed their outer coat.

Specimens used for drawings of the various nymphal instars by C. V. Riley apparently were all in the molting stage, as the figures representing the instars show the nymphs much swollen. These drawings, therefore, are incorrect, even if the insect should have

had only five stages instead of six. The specimens used for the figures in this paper all had fed for some time after casting their last molt. In most cases the specimens were preserved for three, but in some cases for only two days after molting and during this period the individual was permitted to feed. Illustrations of specimens which have just molted and have not fed, or specimens about to molt, are likely to be misleading, as they are not normal representatives of the stage desired. Very often the color pattern of a specimen fades considerably just before molting, and if drawings are made at that time the color pattern for that instar will be wrongly recorded.

The nymphs of the chinch bug during the molting period feed very little, and their color pattern fades toward the close of the period. This fading is due to the loosening of the transparent cuticular layer, which is about to be cast. The darker color pattern of the succeeding instar can often be seen through the thin layer.

FIG. 1.—The chinch bug (*Blissus leucopterus*): Cluster of eggs, showing tubercles at the truncated or blunt ends. Greatly enlarged.

One nymph was caught in the act of casting its skin. When first observed it had already freed part of the abdomen and thorax. It then drew its legs out one at a time and by a jerky motion of the abdomen freed itself entirely from the old skin. The nymph utilized its last pair of legs to push off the skin from the tip of the abdomen.

DESCRIPTION OF THE EGG AND NYMPHAL STAGES.

A description of the egg (fig. 1) and nymphal stages is given below. It does not seem necessary to describe the adult or the sixth instar (fig. 2, *f*), but a brief discussion of the sexual differences in the adult stage is included. It seems important that the sexual differences be known in order to facilitate biological work on this insect.

EGG.

The egg is elongate ovate, slightly reniform in shape, rounded at one end and truncate at the other. The truncate end is supplied with from three to five, usually four, tubercles 0.1 millimeter in length; opaque white in color when just deposited, turning amber in a few days and deep red several days before hatching. Just prior to hatching the embryo shows through the chorion which is smooth, shiny, and somewhat iridescent.

Length, 0.858 mm.; width, 0.308 mm.

FIRST INSTAR.

FIG. 2, *a*.

Head brown; width, 0.235 mm.; eyes dark red; proboscis pale except tip which is dusky; antennal segments dusky, segment 4 of antenna about twice the length of any one of the others, points of articulation pale.

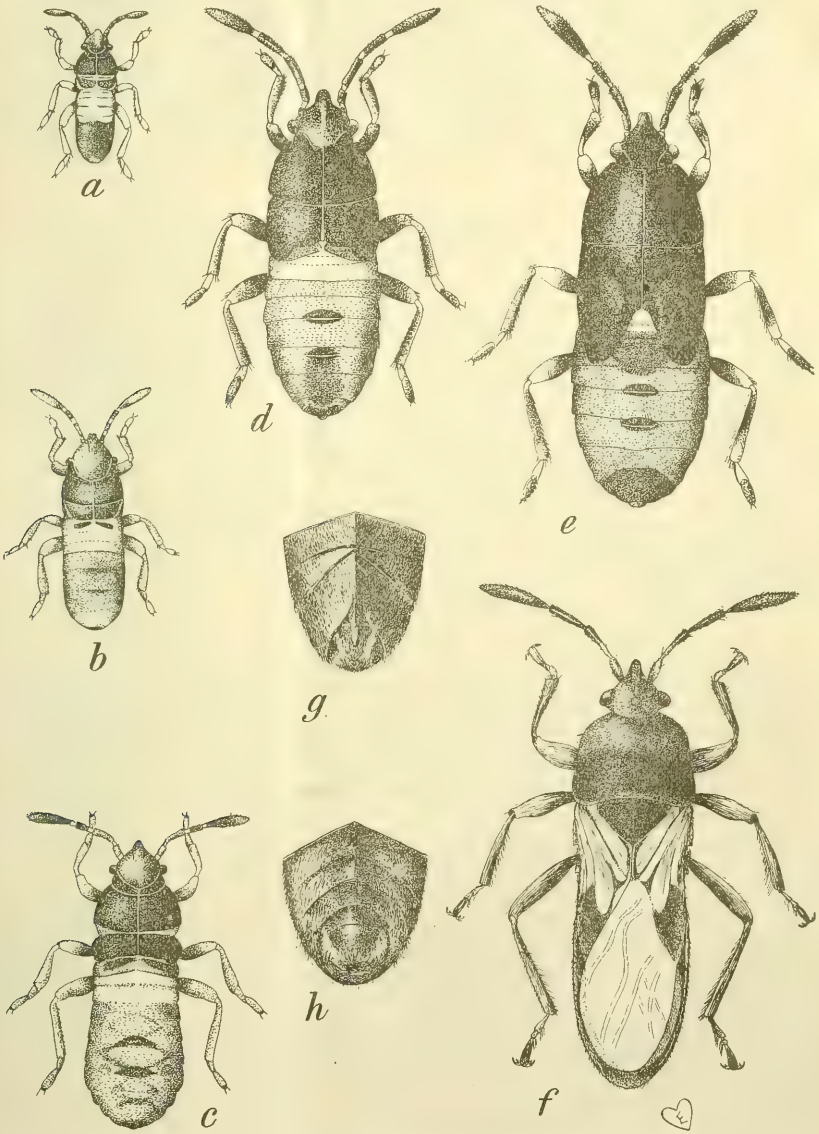

FIG. 2.—The chinch bug: *a*, Nymph, first instar; *b*, nymph, second instar; *c*, nymph, third instar; *d*, nymph, fourth instar; *e*, nymph, fifth instar; *f*, adult of long-winged form; *g*, tip of abdomen of adult female, ventral view; *h*, tip of abdomen of adult male, ventral view. Greatly enlarged.

Thorax 0.234 mm. in width; legs pale, the tarsi distinctly two-jointed; pronotum brown and coriaceous over the whole surface, 0.104 mm. in length; mesonotum pale except the small coriaceous patch on either side of the meson,

which is brown, 0.062 mm. in length; metanotum pale except a narrow dark line on either side of the meson, 0.047 mm. in length. The coriaceous area on the thorax is broken on the meson and causes it to appear as though crossed by a pale line.

Abdomen about the width of the thorax, though sometimes somewhat wider, the widest part being in the region of the fourth segment. Segments 1 and 2 pale yellowish white, this color sometimes invading part of the third segment; remaining segments light red, darkening somewhat in older individuals. There is a minute, dark spot on the meson near the caudal margin of the fourth segment and a similar one on the caudal margin on the meson of the fifth segment. In some specimens these spots are absent during the first instar. Tip of abdomen black.

Length, 0.889 mm.

SECOND INSTAR.

FIG. 2, *b*.

Head brown; width, 0.314 mm.; eyes, antennæ, and beak as in first instar.

Thorax, 0.513 mm. in width; legs pale as in previous instar; pronotum resembling previous instar; mesonotum coriaceous over almost its entire surface; metanotum with two brown coriaceous patches, one on either side of the meson, resembling large exclamation points; otherwise the segment is pale.

Abdomen, 0.502 mm. in width, widest in region of fourth segment. Segments 1 and 2 pale; remaining segments darker red than in preceding instar. The dark spots on the fourth and fifth segments are somewhat larger than in the preceding instar, but have not taken on any definite shape. Tip of the abdomen black, as also the area around the anal opening.

Length, 1.287 mm.

THIRD INSTAR.

FIG. 2, *c*.

Head dark brown; width, 0.399 mm.; eyes very dark red; proboscis amber except at tip, which is almost black; segments 3 and 4 of antennæ black, 1 and 2 amber, segment 4 twice as long as 2 and 3 and over three times as long as 1; points of articulation pale, somewhat translucent.

Thorax, 0.518 mm. in width; legs amber, somewhat dusky on the femora; pronotum, mesonotum, and metanotum dark brown and coriaceous over the whole surface; wing pads discernible on the caudal border of the mesonotum near the outer edges, in the form of a slight extension or outgrowth of the coriaceous covering in this region.

Abdomen, 0.596 mm. in width, widest in region of fourth segment. Segments 1 and 2 pale whitish, remaining segments a dull red, with mottlings of a darker color here and there. The two spots on the abdomen assuming a definite shape somewhat resembling a flaxseed in outline, one spot on the caudal margin on the meson of the fourth segment and the other on the meson of the fifth segment extending partly over the suture of the fifth and six segments. Tip of abdomen black.

Length, 1.648 mm.

FOURTH INSTAR.

FIG. 2, *d*.

Head, eyes, antennæ, and proboscis the same color as in the preceding instar; width of head, 0.465 mm.

Thorax, 0.654 mm. in width; legs same in color as in preceding instar; mesonotum very narrow, only about half as long as the pronotum and only a

small area of this segment visible on the meson and appearing whitish. Wing pads now conspicuous and extending about half way across the first abdominal segment.

Abdomen, 0.696 mm. in width. Segments 1 and 2 pale whitish as before, remaining segments dark red with streaks of black, giving it a blackish appearance. The black spot on the meson of the fourth abdominal segment very conspicuous. The other spot has moved farther caudad and is now found just below the suture separating the fifth from the sixth abdominal segment, or on the meson of the cephalic border of the sixth segment. Tip of abdomen black, including a small area around the anal opening.

Length, 2.114 mm.

FIFTH INSTAR.

FIG. 2, *e*.

Head black; width, 0.591 mm.; polished; eyes very dark red; proboscis amber, except tip which is black; antennal segment 1 amber, 0.157 mm. long, segment 2 amber, 0.314 mm. long, segment 3 black, 0.282 mm. long, segment 4 black, 0.518 mm. long; points of articulation pale.

Thorax, 0.937 mm. in width; legs dark; femora almost black; tibiæ light amber except tibia of third pair of legs, which is darker; tarsi dark amber; joints lighter. Pronotum, mesonotum, and metanotum black, polished. Wing pads now extending to the caudal margin of the third abdominal segment.

Abdomen, 0.957 mm. in width; widest in region of fourth segment as before. First and second segments not visible except for a small portion on the meson, remainder of these segments covered by the wing pads, whitish. Remaining segments very dark red, almost black, with a number of dark areas and blotches almost black in color, tinged with blue, iridescent. Under the unaided eye the abdomen appears black. There is a velvety area on the meson of the third segment, sometimes extending partly over the fourth segment as well. The black patch which was on meson of abdominal segment 4 in preceding stages is now on the suture separating segments 4 and 5. The other, which was on the meson of the fifth segment in the first, second, and third instars, and on the sixth abdominal in the fourth, is now on the suture separating the fifth and sixth segments. These patches are very conspicuous. The tip of the abdomen is black as well as a considerable area surrounding it; in fact, most of the abdomen caudad of the seventh segment is black.

Length, 2.967 mm.

SEXUAL DIFFERENCES AMONG ADULTS.

The male chinch bug generally is not so large and robust as the female. There are other more conspicuous characters, however, that distinguish the sexes. If the lower, ventral part of the abdomen of either sex is closely examined, it will be noted that the abdomen of the male is rounded (fig. 2, *h*), while that of the female has a distinct ridge on the ventro-meson, giving the abdomen an outline in the form of an inverted V (fig. 2, *g*). Furthermore, the tip of the abdomen in the male is rounded, and surrounding the genital opening, especially along the upper border and the sides, the area is well supplied with moderately long hairs. In the female the last segment on the ventro-meson is adjusted to shield the ovipositor and its mechanism.

A PARASITE OF THE ADULT.

From time to time collections of adults and nymphs of the chinch bug have been made in fields about Rock Hill, S. C., and brought to the laboratory at Columbia, S. C., for breeding work. No special attention was given to the possibility of rearing a parasite from the adult. A large number of adults, however, comprising a portion of the material mentioned, yielded a tachinid parasite which emerged from a male individual. The host specimen was collected by Mr. Samuel Blum on May 7. The puparium was formed on May 8 and the adult fly issued on May 20. The puparium was at first a golden color, later turning a dark red. This parasite has been determined by Mr. W. R. Walton as *Phorantha occidentis* Walk., and the determination has been verified by Dr. J. M. Aldrich of the United States National Museum.

Very little is known concerning this parasite except that it has been reared from two other hosts, both belonging to the order Hemiptera. Mr. F. B. Milliken reared an adult of this species in 1913 from an adult of the false chinch bug (*Nysius angustatus* Uhl.) and Mr. M. D. Leonard reared it from the capsid bug *Miris dolabratus* L. As far as the writer has been able to learn, this is the first record of the rearing of a dipterous parasite from the chinch bug, although a hymenopterous parasite (*Eumicrosoma benefica* Gahan) was reared by Mr. J. W. McColloch of the Kansas Agricultural Experiment Station several years ago from eggs of this species.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 1017

Contribution from the Bureau of Public Roads
THOMAS H. MacDONALD, Chief

Washington, D. C. PROFESSIONAL PAPER. March 31, 1922

REPORT ON DRAINAGE AND PREVENTION OF OVERFLOW IN THE VALLEY OF THE RED RIVER OF THE NORTH.

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Forest V. King, *Drainage Engineer.*

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INTRODUCTION.

That a comprehensive drainage program is essential for the proper development of agriculture in the valley of the Red River of the North was recognized soon after farming began to be extensively practiced in that valley, about 1870. In the spring melting snow and rain combined are apt to cause high floods, which delay spring planting, interrupt traffic on roads and railroads, and greatly hamper business. During the summer heavy storms covering relatively small areas often cause floods which do considerable damage. The watershed has an area of nearly 36,000 square miles, of which 8,500 square miles lie within the valley. The initial effort toward a comprehensive drainage plan was made at a convention at Crookston, Minn., in 1886, when it was arranged to prepare plans for draining six Minnesota counties bordering on the Red River.

Drainage in this valley is an interstate matter because outlets are necessary into the Red River, the Bois de Sioux River, and Lake Traverse, which together constitute the boundary between Minnesota and North Dakota, and a part of the boundary between Minnesota and South Dakota. In 1900, as a result of the disastrous 1897 flood in the valley, a tri-State drainage association was formed among property owners and other parties interested in the welfare

of the valley; and in 1906 an international drainage conference was held at Grand Forks, N. Dak., which was attended by delegates named by the governors of the three States in which the valley is situated and by delegates from Manitoba, Canada. Various plans for obtaining relief from floods and poor drainage conditions have been studied and much time and money have been expended on them. A list of Federal investigations up to 1915 is contained in House Document No. 1666, Sixty-third Congress, third session. Aside from the Federal investigations, numerous State and local organizations have from time to time taken action under the State laws. Some of the projects have led to considerable legal contention. In addition to the fact that any project affecting this watercourse requires the joint action of the three States involved, the official designation of Lake Traverse and the Red River as navigable waterways makes it necessary that any plans for improvement that might affect the regimen of those waterways shall receive the approval of the Secretary of War.

The attention of the Bureau of Public Roads was first called to the project in August, 1916. In October, 1916, the bureau agreed to make a preliminary examination of the project provided the interested landowners should raise a fund to be used for paying certain incidental expenses. In the summer of 1918 a fund of $2,300 was provided by eight county boards. This fund was raised largely through the efforts of Mr. Herbert A. Hard, of the North Dakota Flood Control Commission.

Field work on the project was begun in September, 1918, and was completed in April, 1920. P. T. Simons, senior drainage engineer, was placed in charge of the project. He was assisted in the field by B. S. Clayton, Dan S. Helmick, and F. V. King, all drainage engineers of the bureau, and by Paul Funderhide, drainage assistant. F. V. King, Guy L. Smith, and W. C. Whitney, drainage engineers, assisted in the preparation of the report.

SUMMARY OF RECOMMENDATIONS.

The protection of the valley of the Red River of the North from overflow and the securing of adequate drainage for the low-level lands in the valley require the construction of works—to prevent or to control overflow, and to provide an outlet for the drainage of the entire watershed. Two interstate projects are recommended and several State or local projects suggested.

LAKE TRAVERSE-BOIS DE SIOUX PROJECT.

In the upper portion of the watershed the Lake Traverse-Bois de Sioux project, affecting three States, is proposed to function as follows: (1) By means of a detention reservoir in Lake Traverse run-off would be kept under control, and high-water discharge in the Red

River would be appreciably reduced in that part of the stream above the mouth of the Sheyenne River; (2) by the construction of drainage channels in the territory below the reservoir complete drainage of 112,370 acres of land would be made possible.

The estimated cost of improvements in this project is $1,400,000, approximately $12.50 per acre of land for which drainage outlets would be provided.

RED RIVER PROJECT.

In the Red River Valley proper, below the junction of the Otter Tail and Bois de Sioux Rivers, the Red River project, affecting two States, is proposed. It would function as follows: As a result of improving the river channel and constructing a flood by-pass channel, the discharge capacity of the stream would be so increased as to lower the high-water stages by 5 feet or more. In order to secure these results at the international boundary it would apparently be necessary to continue the channel improvements for about 30 miles (measured along the river) beyond the boundary. The estimated cost of improvements in this project is $4,000,000, or an average of $8 per acre for 500,000 acres of land on which overflow would be prevented.

The completion of the two projects would render the State boundary streams capable of affording outlet drainage for the entire Red River watershed. Moreover, high-water stages would be reduced by 5 feet or more, so that practically no overflow would occur.

STATE AND LOCAL PROJECTS.

Serious overflow occurs along the tributary streams on both sides of the Red River and extensive areas need additional local drainage. In planning the above improvements due allowance has been made for the effects of such future local works. No plans nor estimates in detail for projects along the tributaries are submitted because no interstate problems will be involved. A summary of the Red Lake project, as proposed by the Corps of Engineers, United States Army, is, however, included.

THE RED RIVER VALLEY.

In this report Lake Traverse (see fig. 1) refers to the lake area lying along the State line between Browns Valley, Minn., and White Rock, S. Dak. Bois de Sioux River refers to the watercourse extending from the outlet of Lake Traverse along the State line to Wahpeton, N. Dak. The Red River proper is formed by the junction of the Bois de Sioux River and the Otter Tail River at Wahpeton and extends northward to Lake Winnipeg in the Province of Manitoba, Dominion of Canada. It crosses the international boundary just north of Pembina, N. Dak.

PHYSICAL CHARACTERISTICS.

Lake Traverse, the Bois de Sioux River, and the Red River form a continuous natural watercourse from Browns Valley, Minn., to the international boundary, a distance of 456 miles. From the outlet of Lake Traverse the stream follows a winding course through the center of a flat valley, the general direction of flow being almost due north (see fig. 1). The fall in general is slight and diminishes toward the north (see fig. 2). The surface altitudes above sea level are: 980 feet at Lake Traverse; 963 feet at Wahpeton; 900 feet at Fargo; 830 feet at Grand Forks; 789 feet at the international boundary; and 755 feet at Winnipeg, 62 miles north of the boundary.

TOPOGRAPHY.

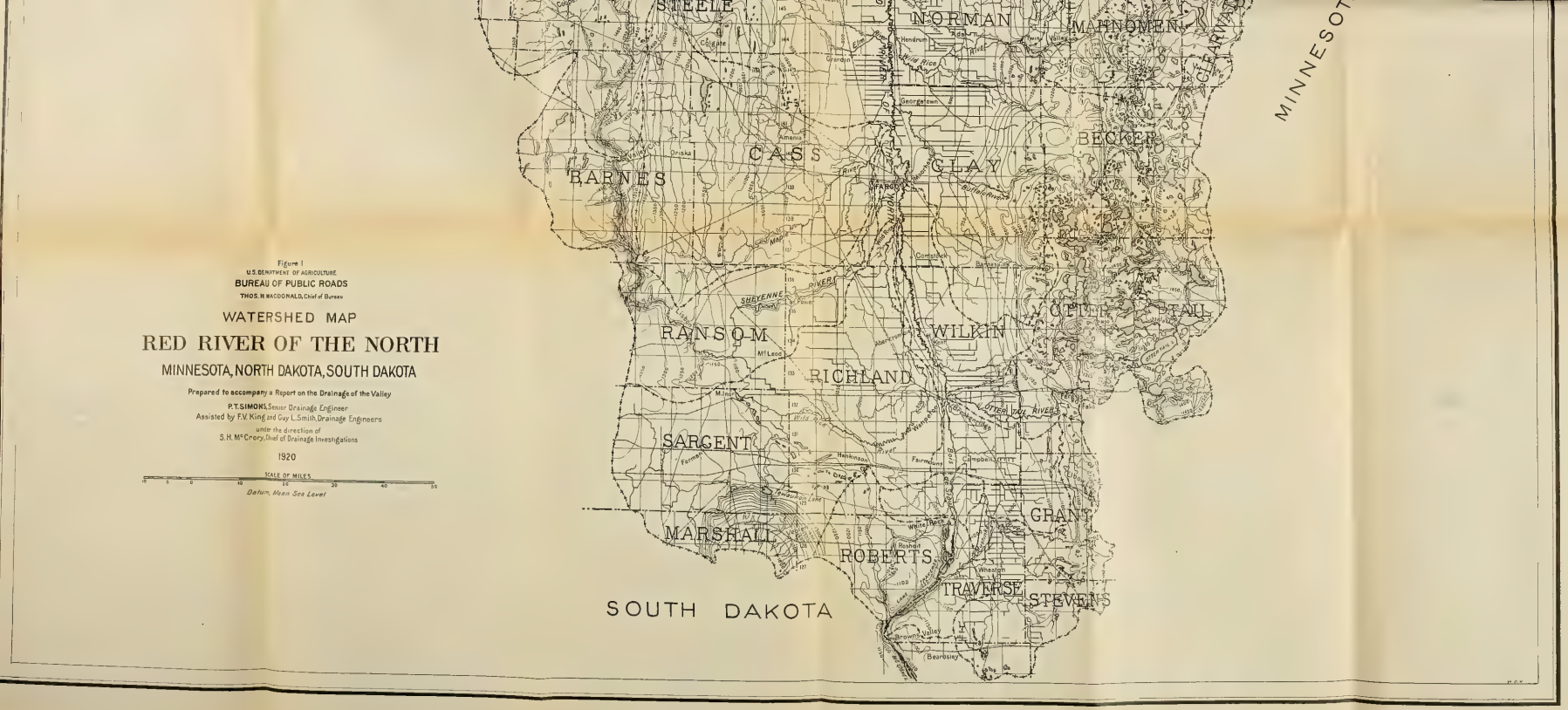
The watershed of that part of the river above the international boundary has an area of 35,895 square miles (fig. 1). It consists of a broad plain flanked on the east and west by higher land. This central plain has a width of from 15 to 30 miles. To the eye the land appears level but it has a certain degree of natural drainage so that it can in no sense be classed as swamp land. The bordering land rises more or less sharply to the higher parts, which are from 300 to 700 feet above the central portion of the basin.

The eastern part of the watershed originally was forested and contained extensive swamps and many lakes. Much of the timber has been cut and the land cleared, so that at present it is estimated that not more than one-tenth of the whole watershed is forested. Probably 80 per cent of the prairie and cleared lands are now cultivated, the remainder being utilized in raising grasses and for town and building sites, drainage channels, highways, and railroads.

GEOLOGICAL ORIGIN.

Geologists state that during the glacial period the entire central portion of the valley was covered by glaciers which were deepest near the center of the valley. The glaciers moved toward the south and the water from them flowed to the south. As the glaciers melted and their southern edges receded, a barrier of earth, sand, gravel, and bowlders formed to the south of Lake Traverse. Water from the melting glaciers accumulated behind this barrier and formed a lake that has since disappeared, which the geologists call Lake Agassiz. There was not, however, sufficient water to erode the barrier south of the lake. The glaciers continued to melt away until finally the water in the lake was enabled to drain away to the north into Lake Winnipeg. Water from the melting glaciers, and that which has been flowing off since the glacial period, eroded and formed the channels of the present watercourses.

MANITOBA
ROLETTE
TOWNER
CAVALIER
PEMBINA
KITTSON
ROSEAU
NORTH DAKOTA
WALSH
MARSHALL
PIERCE
BENSON
NELSON
GRAND FORKS
PENNINGTON
BELTRAMI
UPPER RED LAKE
LOWER RED LAKE
RED LAKE
WELLS
EDDY
SHERIDAN
GRIGGS
TRAILL



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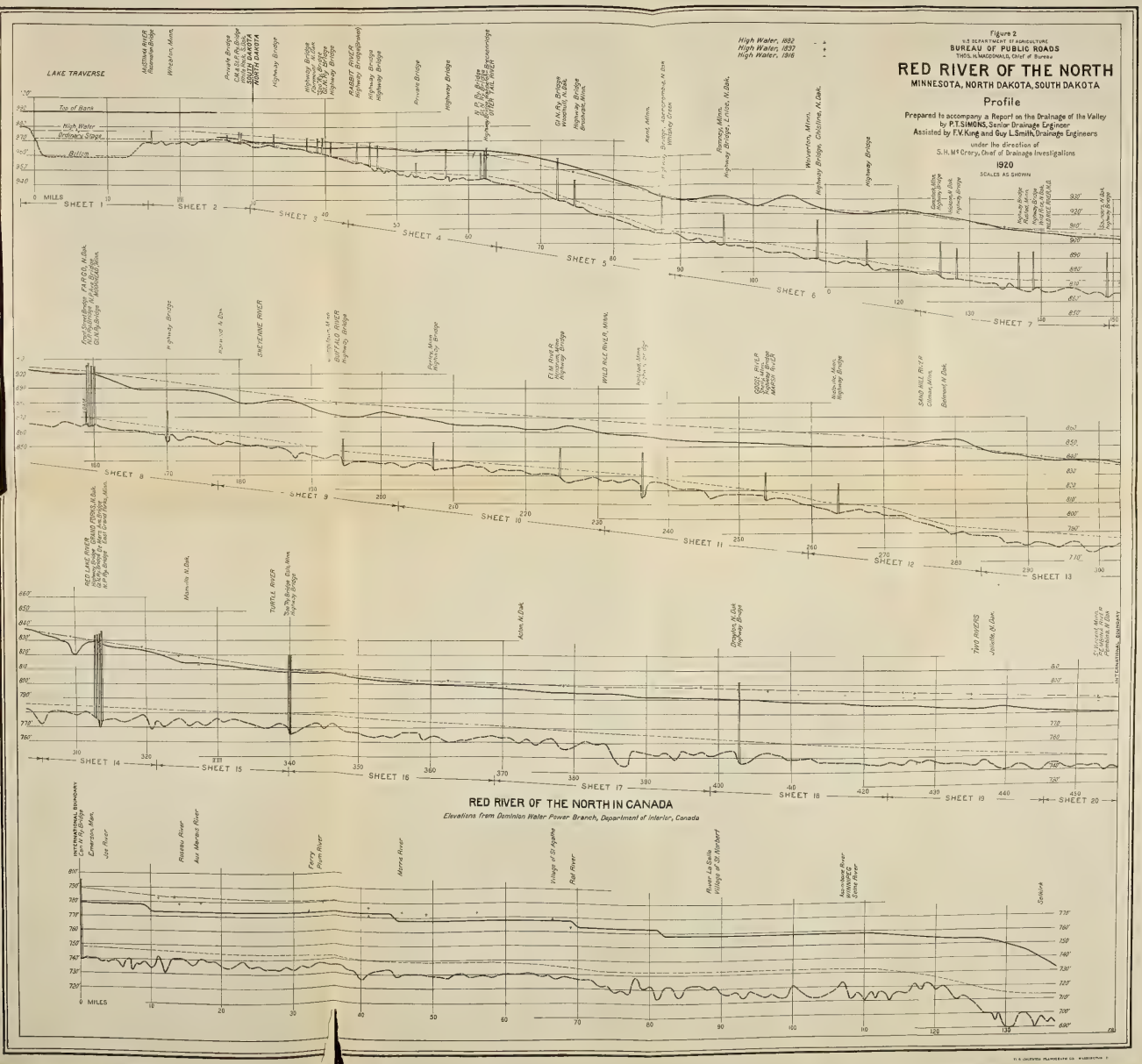

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The glaciers eroded the hills that then existed and filled the valleys. Rocks were ground into gravel and sand. As the glaciers receded to the north the materials deposited by them were further reduced by waves and currents in the lake. The streams brought down silt which was deposited in the lake. In this manner were formed the topographical features and the soils now found in the watershed of the Red River.

SOIL.

The soils throughout the former glacial lake bed are deep, heavy, finely divided, well-compacted mixtures of clay, loam, and small proportions of very fine sand. For the first foot or more this mixture is deeply blackened by decayed organic matter. The soils of the valley are classified by the United States Bureau of Soils (Bulletin 96, 1913) as the Fargo series of soils. Six types are mentioned: Clay loam, fine sandy loam, loam, fine sand, clay, and silt loam comprise the principal areas. In their natural condition most of these soils are poorly drained. All are fertile and, when drained, admirably adapted to agricultural purposes. The soil of the upper levels of the watershed is less uniform in quality and somewhat less productive than that of the central valley, but through drainage, clearing, and proper farming methods practically all can be developed into excellent farm land. Along the edges of the central plain are found moraines and shore lines of the former lake. These are long, low ridges of sand or gravel from a few hundred feet to a half-mile in width. Such land has less agricultural value than any other in the watershed.

WATERSHEDS.

The watersheds of the Red River and its tributaries are shown in figure 1, and their areas are given in Table 1.

The Red River watershed has been subdivided as indicated on the map and in the table, for the purpose of comparing the precipitation, temperature, topography, soil, vegetation, and natural and artificial drainage of the different portions, as affecting run-off in the valley.

UTILITY OF THE WATERCOURSES.

Of the various ways in which the Red River and its tributaries prove useful and valuable to the community the more important are the removal of excess water, water supply, sewage disposal, water power, and recreation. Commercial navigation although in earlier days of great importance has decreased until at present it is insignificant. Commercial fishing is carried on to some extent in different parts of the watershed but the industry is of minor importance in the State boundary waters. Irrigation by water drawn from the streams has been considered, but it has been found that where con-

TABLE 1.—*Watershed areas of the Red River of the North and tributaries.*

Tributary streams.							Red River of the North-Boise de Sioux River-Lake Traverse.				
Stream.	Station.	Areas of watersheds in square miles.				Increment to main stream.	Areas of watersheds in square miles.				Station.
		South Dakota.	Minnesota.	North Dakota.	Total.		South Dakota.	Minnesota.	North Dakota.	Total.	
Small streams	Mustinka River mouth	219	72		291	291	219	72		291	Just above mouth of Mustinka.
Mustinka River	Wheaton, Minn		756		756						
Do	Mouth		852		852	852	219	924		1,143	Just below mouth of Mustinka.
Small streams	White Rock, S. Dak	131	12	49	192	192	350	936	49	1,335	White Rock, S. Dak.
Do	Fairmount, N. Dak	10	45	90	145	145	360	981	139	1,480	Fairmount, N. Dak.
Do	Wahpeton, N. Dak		364	31	395	395	360	1,345	170	1,875	Wahpeton, just above mouth of Otter Tail.
Otter Tail River	Fergus Falls, Minn		1,300		1,300						
Do	Breckenridge, Minn		1,840		1,840	1,840	360	3,185	170	3,715	Breckenridge, just below mouth of Otter Tail.
Small streams	North Dakota Wild Rice River mouth.		375	70	445	445	360	3,560	240	4,160	Just above mouth of North Dakota Wild Rice.
North Dakota Wild Rice River.	Lake Tewaukon	215		410	625						
Do	Mouth	310		1,900	2,210	2,210	670	3,560	2,140	6,370	Just below mouth of North Dakota Wild Rice.
Local drains	Fargo-Moorhead		40	25	65	65	670	3,600	2,165	6,435	Fargo-Moorhead.
Do	Sheyenne River mouth		45	50	95	95	670	3,645	2,215	6,530	Just above mouth of Sheyenne.
Sheyenne River	Valley City, N. Dak			4,185	4,185						
Do	Haggart, N. Dak			5,600	5,600						
Do	Mouth			7,400	7,400	7,400	670	3,645	9,615	13,930	Just below mouth of Sheyenne.
Buffalo River	Georgetown, Minn		1,175		1,175						
Minnesota Wild Rice River.	Twin Valley, Minn		835		835						
Do	Mouth		1,485		1,485						
Goose River	do			1,270	1,270						
Sandhill River	do		425		425						
Small streams	Sheyenne River to Grand Forks.		485	1,200	1,685	6,040	670	7,215	12,085	19,970	Grand Forks, just above mouth of Red Lake River.
Red Lake	Outlet of Red Lake		1,950		1,950						
Thief River	Thief River Falls		1,080		1,080						
Red Lake River and Thief River.	do		3,600		3,600						
Clearwater River	Red Lake Falls		1,330		1,330						
Red Lake River	Crookston, Minn		5,320		5,320						
Do	East Grand Forks, Minn		5,785		5,785	5,785	670	13,000	12,085	25,755	Grand Forks, just below mouth of Red Lake River.
Turtle River	Mouth			705	705						
Forest River	do			1,030	1,030						
Snake River	do		760		760						

Park River	do			885	885						
Tamarac River	do		365		365						
Small streams	Grand Forks to Drayton		595	170	765	4,510	670	14,720	14,875	30,265	Drayton, N. Dak.
Two Rivers	Hallock, Minn		635		635						
Do	Mouth		975		975						
Small streams	Drayton to Emerson, Manitoba, Canada.		370	420	790						
Pembina River	Neche, N. Dak	1,995		1,325	3,320						
Do	Pembina, N. Dak	1,995		1,870	[1] 3,865	[1] 5,630	670	16,065	17,165	[1] 35,895	International boundary.

[1] Includes 1,995 square miles of Canadian territory.

ditions of flow are suited for this purpose there is no need for irrigation.

Under the conditions existing in this valley the most important function of the watercourses is the removal of excess water. This constitutes a combined problem of drainage and flood control which is of vital interest over practically the entire watershed. This problem is discussed later in the report.

The Red River and its tributaries are the source of the water supply for nine cities and towns having a total population of about 69,000. The most important considerations in the use of streams for municipal water supply are the quantity and quality of the water. It is not sufficient that the total amount of water passing through the stream channel during the year be great enough to supply demands; the flow must be so distributed, either naturally or by artificial means, that at no time will it fall below a minimum consistent with safety. To insure a sufficient degree of dilution of impurities and provide for future increased demands, this minimum flow should always be many times greater than the rate at which the water is withdrawn from the stream for use. In populated districts stream water is seldom of such quality that it can safely be used for domestic purposes without treatment. Where the streams furnish the water supply the flow is abundant except at certain points on the Red Lake River where the flow during exceedingly dry seasons becomes so small as to occasion concern over the concentration of impurities. The increase in minimum flow planned for this river as a part of the Red Lake project would improve this condition. In some of the smaller tributaries the dry-season flow is so slight that water supply from this source is impracticable. In most cases the water taken from the streams is passed through filters which remove the greater part of the suspended impurities, and in the upper parts of the streams such treatment is sufficient to render the water fit for use. However, the water of this drainage basin is very "hard," owing to salts leached from the ground, and can be much improved for domestic use by softening through chemical treatment. In the lower parts of the streams where the accumulation of impurities from above is greater, chemical treatment also is necessary especially during low-water periods, to assure absence of organisms dangerous to health. Fargo and Grand Forks are now operating plants for such treatment of the water, and it is probable that, as the cities along the streams grow and become more numerous, chemical treatment will be commonly resorted to.

The streams in the Red River basin are more used as a means of sewage disposal than for water supply. By dilution and by the action of natural purifying agencies, obnoxious and dangerous effects of this contaminating content are eliminated or

greatly reduced. Yet when quantities of sewage are poured into streams beyond their ability to dilute and purify, a nuisance and menace is created and artificial means of preventing contamination become necessary. Red River and its tributaries have in the past carried enough water to dilute the sewage discharged into them, and the sewer outlets have been separated widely enough to allow sufficient exposure to the purifying effects of air, sunlight, and bacterial action. Where stream water has been used for municipal water supply, the intakes have been far enough below sewer outlets to allow partial purification, making it more economical to purify the water withdrawn for use than to treat the sewage before its entry into the streams. In a few cases conditions in the streams below sewer outlets have become bad during the summer low-water periods, and some attempts at sewage treatment have been made. Moreover, trouble has been caused at places by water backing up into sewer mains during flood stages. There is no doubt that with increasing population and the growing use of the streams for water supply, sewage treatment will become necessary in most of the sewerage systems. Indeed, inspection of the streams during dry periods indicates that such necessity will not be long delayed.[1]

Owing to the slight fall of the stream bed, the impossibility of storage, the irregularity of flow, and the occurrence of long-continued low-water stages, the Red River is totally unsuited for economical water-power development. Conditions in the tributary streams, on the contrary, favor such development. The rapid fall of 300 to 500 feet by which streams from both sides reach the central valley seems to afford opportunity for considerable power development, yet owing to light precipitation over the western part of the watershed the streams entering from that side lack sufficient flow to develop profitable, continuous power. A few small plants are in operation, but extensive development is prevented by long periods of low flow and lack of yearly precipitation great enough to provide the storage necessary for continuous operation of power plants. It is on the eastern tributary watersheds that most of the power developments are located, and there the greatest possibilities for future development exist. The annual precipitation is much greater than in the western part and more favorably distributed through the year. The streams have consequently a much greater and more uniform flow. Many of the valleys have such slopes that by properly locating dams sufficient water can be stored to provide flow enough throughout the year for the profitable operation of power plants. Power has been developed on the Otter Tail, Minnesota Wild Rice, and Red Lake Rivers, and on certain smaller streams. At present there is in oper-

[1] Quarterly Journal of the University of North Dakota, Vol. IX, No. 3, April, 1919. Elwyn F. Chandler.

ation over 3,000 horsepower and, according to Chandler's estimate,[2] by utilizing the storage possibilities in the headwaters of the streams a total of between 100,000 and 200,000 horsepower can be developed throughout the year.

In the way of recreation the streams and lakes provide swimming, fishing, boating, and skating. The wooded banks of the waterways are well suited for camping. In the cities and towns tracts adjoining the streams have been reserved for public use, and fine parks and playgrounds are numerous throughout the settled districts.

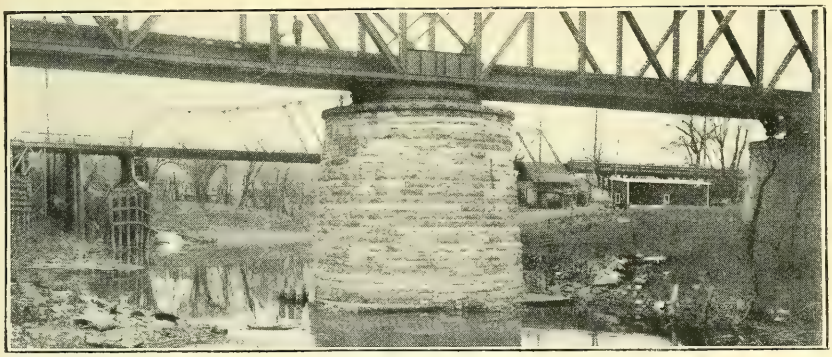
To utilize their various possibilities, it is often necessary to regulate by artificial means the regimen of streams. This has been done in the streams of the Red River watershed in the interest of water-power and drainage, especially in connection with drainage. The regulation and control of run-off is of more importance in its relation to the development of drainage and flood control in the valley than in connection with any other services which the streams perform. Consequently no changes should be made in the regimen of the waterways, in the interests of the minor services, that would be adverse to the drainage interests.

WATER TRANSPORTATION.

Water transportation on the Red River was carried on as far south as the junction of the Otter Tail and Bois de Sioux Rivers at Breckenridge. The early traders used the stream as a lane of travel and for the transportation of articles of trade and supplies. When the valley became somewhat settled supplies were hauled by ox team from St. Paul to the river and thence by boat to their destinations. As the country developed, this traffic increased greatly as the river furnished the best means of transport then available up and down the valley. With the coming of railroads and improved facilities for moving freight to and from points on the river a further impetus was given to water transportation; but, with the building of railroads along the river, stream navigation began to decline, and it has gradually fallen off until at present, with railroad lines following the river on both sides for its entire length within the United States, water transportation has practically ceased. The low-water years of 1911 and 1912 stopped commercial navigation of the river, and since then it has not been revived (see House Doc. No. 1666, 63d Cong.).

At and north of Fargo all permanent highway and railroad bridges have been constructed with movable spans over the deepest portion of the channel to accommodate the passage of boats, but since there are no boats on the river the bridges are never opened. Plate I and

[2] "The Red River of the North," by Elwyn F. Chandler, Quarterly Journal, University of North Dakota, April, 1911.

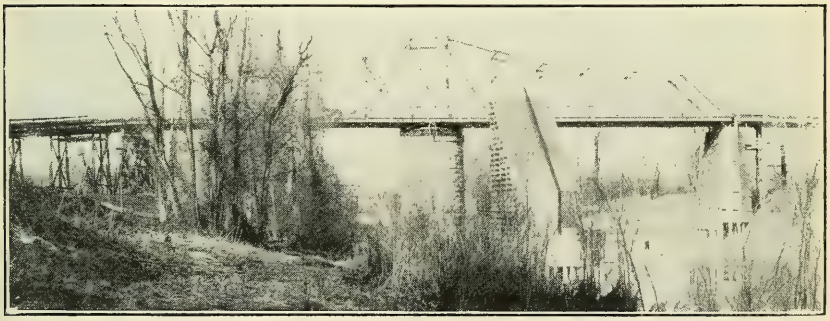


B. P. R.-D-4133

FIG. 1.—LOOKING UP CHANNEL OF THE RED RIVER OF THE NORTH AT NORTHERN PACIFIC RAILWAY BRIDGE BETWEEN MOORHEAD, MINN., AND FARGO, N. DAK., SHOWING LOW STAGE OF WATER DURING THE FALL OF 1910.

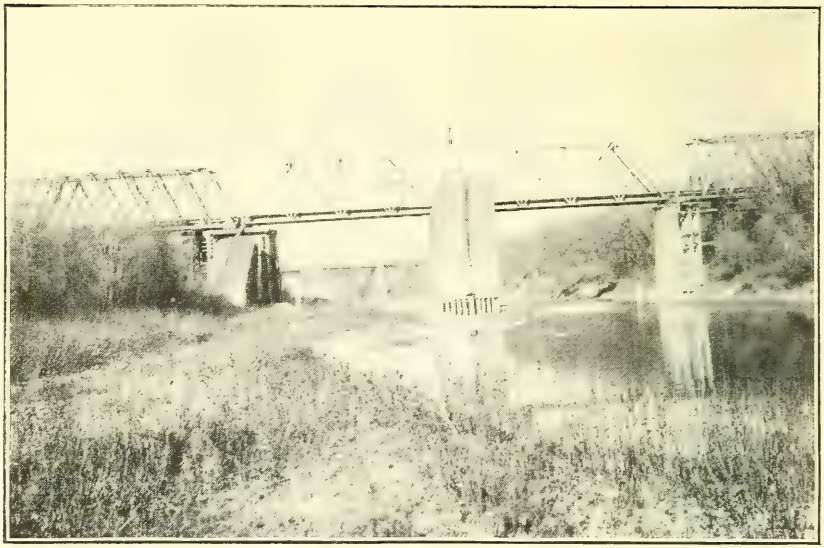
B. P. R.-D-3972

FIG. 2.—LOOKING DOWN THE RED RIVER OF THE NORTH FROM THE NORTHERN PACIFIC AVENUE HIGHWAY BRIDGE, FARGO, N. DAK. NOTE OBSTRUCTION TO FREE FLOW IN CHANNEL BY GUIDE PIER AND TREES. AUGUST, 1919.



B. P. R.-D-2003

FIG. 3.—LOOKING DOWN THE RED RIVER OF THE NORTH FROM POINT JUST ABOVE MOUTH OF RED LAKE RIVER, GRAND FORKS, N. DAK., NOVEMBER, 1918.



B. P. R.-D-2004

FIG. 1.—LOOKING DOWN RED RIVER OF THE NORTH FROM POINT JUST ABOVE GREAT NORTHERN RAILWAY BRIDGE AT GRAND FORKS, N. DAK., NOVEMBER, 1918. NOTE OBSTRUCTION OF FLOW BY TREES ON BOTH SIDES.

B. P. R.-D-1927

FIG. 2.—SHIPPING GRAIN ON LAKE TRAVERSE AT DIAMOND, S. DAK., IN OCTOBER, 1918.

Plate II, figure 1, show some of the bridges and typical low-water conditions which prevail during several months each year.

The Bois de Sioux River never has been used for water transportation. The fact that it is not a navigable stream is officially stated in the report of a preliminary examination of Traverse and Bigstone Lakes by the Corps of Engineers, United States Army (see House Doc. No. 199, 65th Cong.). Lake Traverse is navigable for a distance of about 12 miles between grain elevators of Diamond, S. Dak., and Browns Valley, Minn., and boats operate between these points (see Pl. II, fig. 2). The only tributary stream on which commercial navigation reached important proportions is Red Lake River, including Red Lake. Transportation on this waterway consisted mainly of log-running and a small amount of freight and passenger service. This traffic decreased with the decline of logging operations and at present has practically ceased.

SURVEYS AND OTHER INVESTIGATIONS.

The surveys and other investigations by the Bureau of Public Roads were conducted with the constant aim of obtaining as comprehensive an understanding as possible of all factors that now, or that may in the future, affect the drainage and flood situation in the Red River Valley. This necessitated a thorough study of past and probable future precipitation and run-off, and the other influencing factors. Flood conditions were studied with respect to causes, magnitude, extent of damage, probable recurrence, and methods of control and prevention. The possibilities of reclaiming and improving the wet and flood-affected lands were given careful consideration as were also the general efficiency of existing drainage systems and the question of further development of local drainage. Various plans for improving drainage in general and for the control and prevention of floods were studied with a view to selecting the most practicable and advantageous combinations applicable in this watershed. Suggestions in regard to the form of organization best adapted to carrying on the work are made in the following pages.

The measures recommended are of two classes—those the character or design of which is affected by the run-off from territory lying in more than one State, and those designed to remedy evils resulting from local conditions only.

The work in the field was begun in September, 1918, and was continued for practically one year. It was the original intention to make a detailed survey only of the Bois de Sioux-Lake Traverse region, depending on records of former surveys for data concerning the remainder of the valley; but as the work progressed it became apparent that in order to obtain sufficient information to permit an intelligent study of the project, field work would be necessary along the Red River as far north as the international boundary.

THE RED RIVER SURVEY.

A traverse was run along the Bois de Sioux and Red Rivers from the lower end of Lake Traverse to the international boundary, a distance of about 435 miles. This traverse was tied in to section and township corners at all township lines. South of Wahpeton the lines were run by needle, while north of Wahpeton azimuth was used. The traverse was tied to the range lines. As accurate maps of Lake Traverse and surrounding areas were available, a survey of that part of the valley was not necessary.

LEVELS.

All elevations are referred to mean sea level, the survey having been based upon bench mark elevations as determined by the United States Coast and Geodetic Survey in the 1912 adjustment. Ties were taken to permanent bench marks set by the Coast and Geodetic Survey and the Geological Survey at various points in the valley, the elevations of which are given in Table 2.

TABLE 2.—*Permanent bench marks used in Red River survey.*

(U. S. Coast and Geodetic Survey datum, 1912 adjustment.)

Authority.	Reference.	Location.	Description.	Elevation.
U. S. G. S.	U. S. G. S. Bull. 643.	White Rock, S. Dak.	At front doorway of store of S. E. Oscarson, in top surface of sandstone step; bronze tablet.	975.992
Do	U. S. G. S. Bulls. 469 and 560.	Wahpeton, N. Dak.	Southeast corner of courthouse yard; iron post, stamped "964W."	963.495
U. S. C. & G. S.	U. S. G. S. Bull. 560.	Glyndon, Minn.	About 1 mile south of Glyndon, 11 telegraph poles south of milepost 18, at southwest corner of grade crossing, 4 meters south of a telegraph pole and in range with the poles; bottom of hole in concrete post (C. & G. S. b. m. V 4).	923.889
U. S. D. A.		Fargo, N. Dak.	Agricultural College administration building, lowest section of red sandstone coping, on west balustrade at main entrance; bench mark is 6.4 feet below doorsill and 2.6 feet above surface of ground. Cross cut in center of coping.	902.65
U. S. C. & G. S.	U. S. G. S. Bull. 560.	Hadler, Minn.	4 telegraph poles south of sign board, 3 meters south of milepost 53, in range with telegraph poles, 12 meters west of track; top of copper bolt (C. & G. S. b. m. J5).	900.401
Do	Letter	East Grand Forks, Minn.	Near the southwest corner of the southeast footing of the city steel water tank, across the street from the Great Northern Station. A ¾-inch copper bolt set in lead or cement and flush with a horizontal or vertical surface.	833.689
Do	do	Grand Forks, N. Dak.	8 inches north of the southwest corner of the post-office building, in the granite foundation wall, 1.3 meters above the ground. A 3-inch red metal disk.	834.913
U. S. D. A.		Pembina, N. Dak.	West bank of Pembina River north of road leading to ferry, in yard of Sheriff Atkinson; U. S. G. S. iron bench mark post.	790.45
Can. Geod. Survey.	Geod. Survey of Canada, Vol. I, No. 3, 1913.	Emerson, Manitoba.	In second course of stonework above ground in east wall of Emerson Post Office, 3 feet from south east corner of building.	787.361

The elevations of the United States Coast and Geodetic Survey bench marks are the result of the latest (1912) adjustment of the precise leveling done by that survey in 1906. At that time the elevations of some of the United States Geological Survey bench marks were redetermined by this precise leveling and the others in the vicinity were adjusted to agree. Since then, the leveling of the Geological Survey in the valley has been based upon the Coast and Geodetic Survey elevations, so that at the present time the elevations of all bench marks of both surveys, as used in this investigation, accord with the latest adjustment of the precise leveling results.

Most of the leveling was done with wye levels. A small part along the Bois de Sioux was done with transits. All levels were required to check within the usual limits of error for wye level work. Base-level lines were run for the entire length of the Bois de Sioux and Red Rivers within the United States, and elevations at frequent intervals were taken of the river bed and banks. From the site of the proposed detention dam northward as far as Wahpeton all land that is affected by floods was covered by the level parties, elevations for the most part being taken along section lines. These areas are shown on sheets 2, 3, and 4, figure 3. Over the remainder of the valley the leveling was confined to the immediate vicinity of the river channel and to ties to various bench marks and points of former surveys.

CROSS SECTIONS.

Cross sections of the Bois de Sioux and Red Rivers were taken along the whole length at intervals of approximately one mile, and at all bridges (see fig. 4). The valley was cross-sectioned at the sites of the proposed levee at Browns Valley and the detention dam near White Rock. Test borings were also made at the latter point. A few cross sections of the Otter Tail, North Dakota Wild Rice, Sheyenne, and Red Lake Rivers were taken.

HIGH-WATER DATA.

Special effort was made to locate all reliable high-water marks, both those left by the water or ice on trees, bridges, etc., and those which were set by observers as permanent records. The field parties were constantly on the lookout for reliable information as to high water and from time to time special field trips were made by engineers for this purpose. The elevations of all authentic high-water marks found were taken, and are shown on figure 3, sheets 1 to 20.

STREAM GAUGING.

Staff stream gauges were established at Haggart and Valley City, N. Dak., on the Sheyenne River; at Wild Rice, N. Dak., on the Dakota Wild Rice; and near Fairmount, N. Dak., on the Bois de

Sioux. Records at these stations were kept and were filed with those available from stations previously established. At Haggart the gauge was adjusted to the same datum as that of the United States Geological Survey gauge for which records are available from 1902 to 1906. The stream flows at these gauges were measured by means of Price current-meter determinations during the summer of 1919, and in addition measurements were made at the Fairmount and Wild Rice gauges during the spring high water in 1920. Ratings during high-water stages were obtained at Valley City and Haggart on the Sheyenne River during the spring of 1919.

INSPECTION.

Much information was gathered from many sources from field trips to the various parts of the watershed. Especial attention was given the Bois de Sioux and Red Rivers with respect to channel conditions, bridges, high-water marks and flood effects. The camera was freely used in recording conditions bearing on the project. The drainage and flood situations in general were discussed with well-informed residents. Inquiries were made of engineers, farmers, and other interested persons as to the effectiveness of existing drainage systems, the defects in design and construction, the need for additional drainage and the general sentiment regarding its development. Ditch systems were inspected and investigated as to efficiency, state of preservation, completeness of development, and provision for maintenance. Locations which seemed to offer opportunity for reservoir storage were visited and examinations made as to the practicability of their development. Many maps, old photographs, newspapers, historical documents, and records of various kinds were collected and filed for use in the preparation of this report.

PROGRESS REPORT.

At the request of parties especially interested in the Lake Traverse-Bois de Sioux region, a progress report was prepared and distributed in February, 1920, setting forth the results of the study of that part of the project and the conclusions drawn as to advisable measures for relief in that territory. All essential information contained in the progress report is included in this report.

SOURCES OF INFORMATION.

In addition to the data obtained first hand in the field, information of great value was obtained from many sources. In preparing the maps free use was made of such existing maps as would add to the completeness and accuracy of the work. Information concerning past high-water stages and floods was secured from such sources as histories of the early settlement of the country; various reports

and papers by early settlers, traders, and explorers; and photographs and old newspaper accounts of floods. The investigation of drainage development was aided by maps and records of the States, counties, and districts prosecuting such projects. Records and maps compiled by the various agencies of the Federal Government furnished valuable data concerning precipitation, run-off, temperature, geography, and geology.

MAPS AND PROFILES.

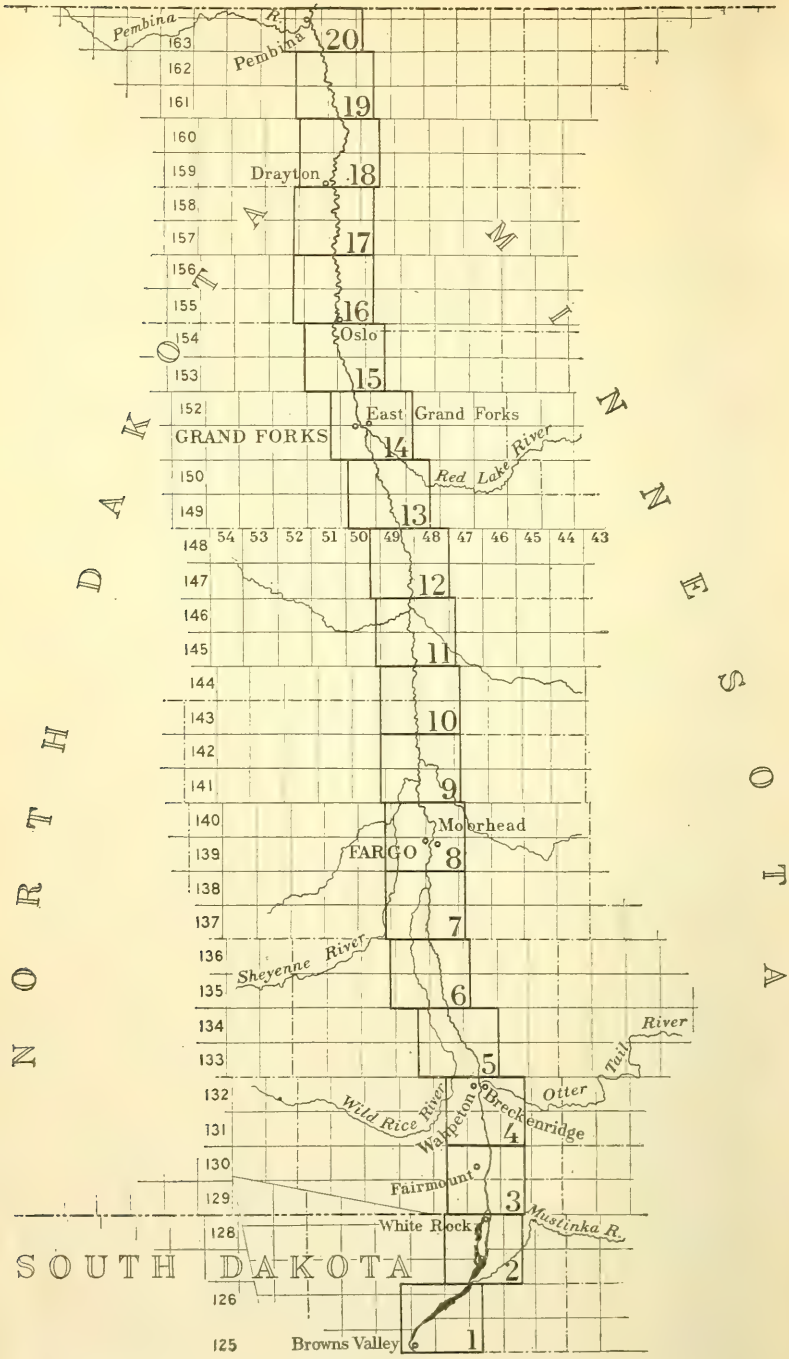
The detail map (fig. 3, sheets 1 to 20) was made up as far as possible from data taken in the field, but as the field work was for the most part done along the main watercourse it was necessary to depend on other maps for information concerning backlying areas. The portions of the map (fig. 3) based on the surveys represent true conditions perhaps more accurately than do the other portions. Features of the map not determined by survey were taken from the best maps available, the data being carefully coordinated and adjusted.

The surface elevations shown are considered equal in accuracy to the general leveling along the river, with the exception of those a mile or more back from the river on the east side from Breckenridge, Minn., to the north line of Marshall County. While these latter elevations are as nearly correct as could be determined from the available data and are considered satisfactory for the purpose of this investigation, there is some doubt as to the degree of accuracy, and they should not be used in preparing plans for local drainage projects without being carefully checked. The General Land Office and Geological Survey plats were freely used in connection with notes of the survey work. War Department maps of Lake Traverse furnished considerable data in that vicinity. For territory not covered by Federal Government agencies, State, county, railroad, and various other maps were used. The locations of artificial drainage systems were supplied from local drainage plats, county and State maps, and drainage district records. Surface elevations, in addition to those taken directly in the field, were obtained from the Geological Survey maps and from ties to other surveys of which plats showing surface elevations were available.

A profile of the watercourse showing stream-bed and bank elevations, bridges, high-water marks, etc., was drawn, and selected cross sections of the river were plotted. The profile and cross sections (figs. 2 and 4) were prepared from data obtained in the field.

PRECIPITATION AND RUN-OFF RECORDS.

An extended study was made of precipitation records with the view of determining past and probable future intensity and distribution of precipitation as factors influencing run-off. The results



Index map to figure 3.

R. 50 W.
R. 49 W.
R. 48 W.
R. 47 W.
T. 126 N.
T. 125 N.
Diamond
Carlson Island
Jackson Island
Jensen Island
LAKE TRAVERSE
SOUTH DAKOTA
MINNESOTA
Lake Bdesaka
Jim Creek
Eighteen Mile Creek
ROBERTS CO.
TRAVERSE CO.
LITTLE MINNESOTA RIVER
Iron Monument
Browns Valley
G. N. RY.
TRAVERSE CO.
BIG STONE CO.
Figure 3
SHEET 1 of 20 Sheets
U.S. DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS
THOS. H. MACDONALD, Chief of Bureau
RED RIVER OF THE NORTH
MINNESOTA, NORTH DAKOTA, SOUTH DAKOTA
Prepared to accompany a Report on the Drainage of the Valley
by P.T. SIMONS, Senior Drainage Engineer
Assisted by F.V. King and Guy L. Smith, Drainage Engineers
under the direction of
S. H. McGrory, Chief of Drainage Investigations
1920
SCALE OF MILES
SCALE OF FEET
Proposed Levee
High Water Line
Line 5 ft. above High Water
Edge of Swamp
Mile Numbers
Surface Elevations, also Ice and Water 9610
Bottom Elevations (179.3)
High Water Elevations U.W. 1682 977.7
Cross Sections
Size of Ditches Bottom Width Depth
Datum, Mean Sea Level, U.S.C. and G.S., 1912 Adjustment

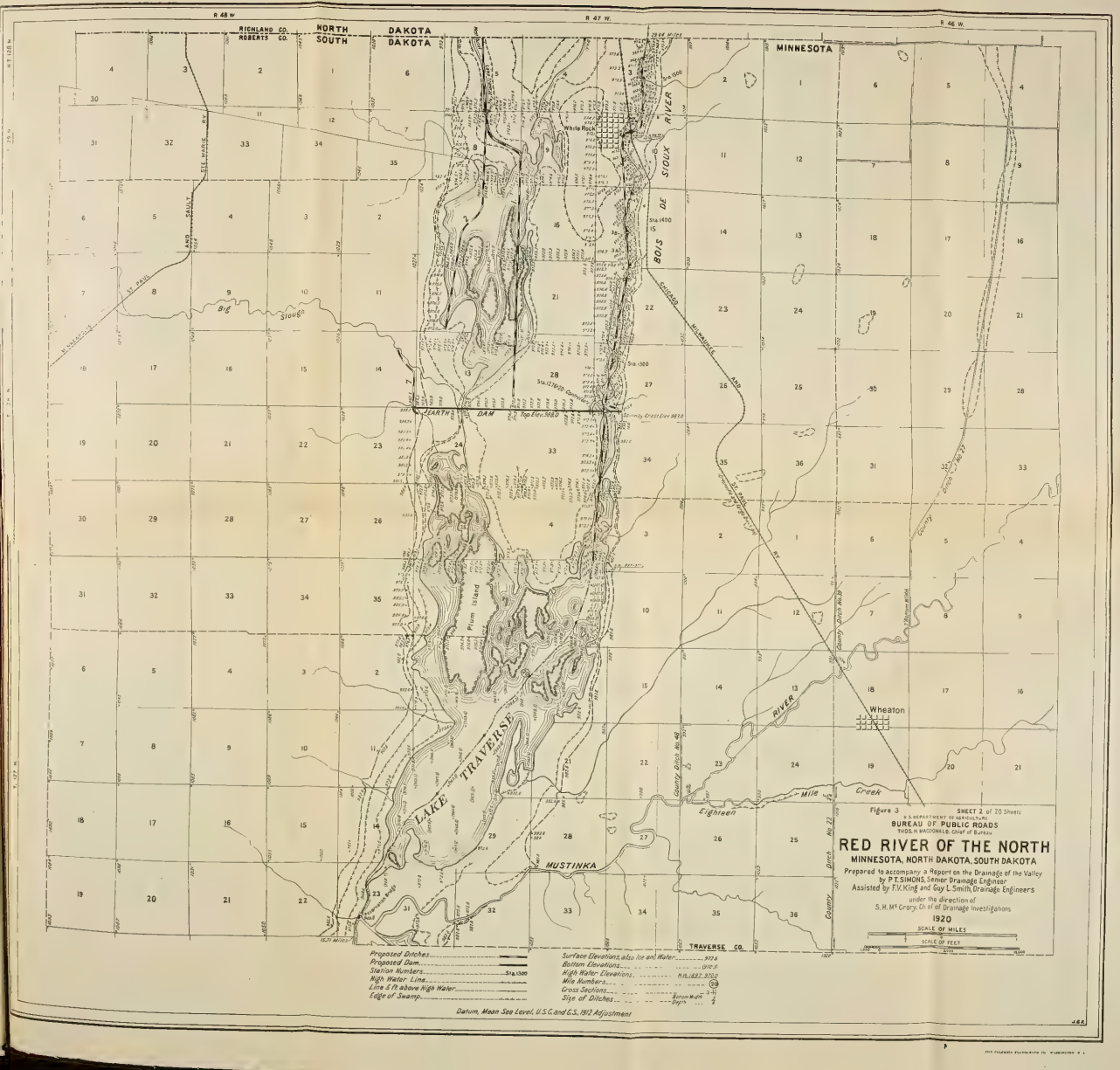


Figure 3 SHEET 2 of 20 Sheets

U. S. DEPARTMENT OF AGRICULTURE
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THOS. H. MACDONALD, Chief of Bureau

RED RIVER OF THE NORTH

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Bul. 1017, U. S. Dept. of Agriculture

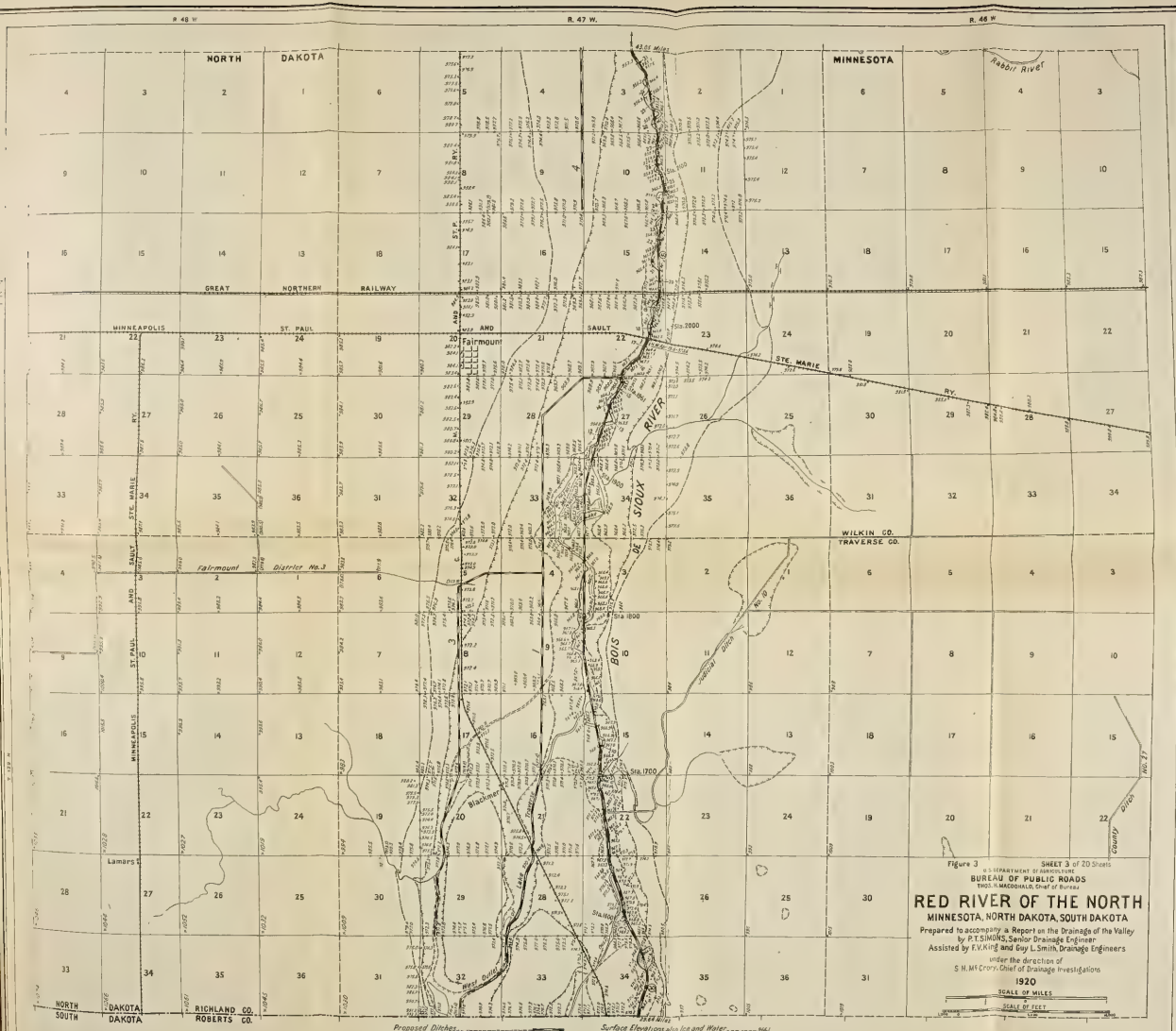

Figure 3 SHEET 3 of 20 Sheets

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1920

SCALE OF MILES
SCALE OF FEET

THE COLUMBIA PLANOGRAPH CO., WASHINGTON, D. C.

B.A. 1017, U. S. Dept. of Agriculture

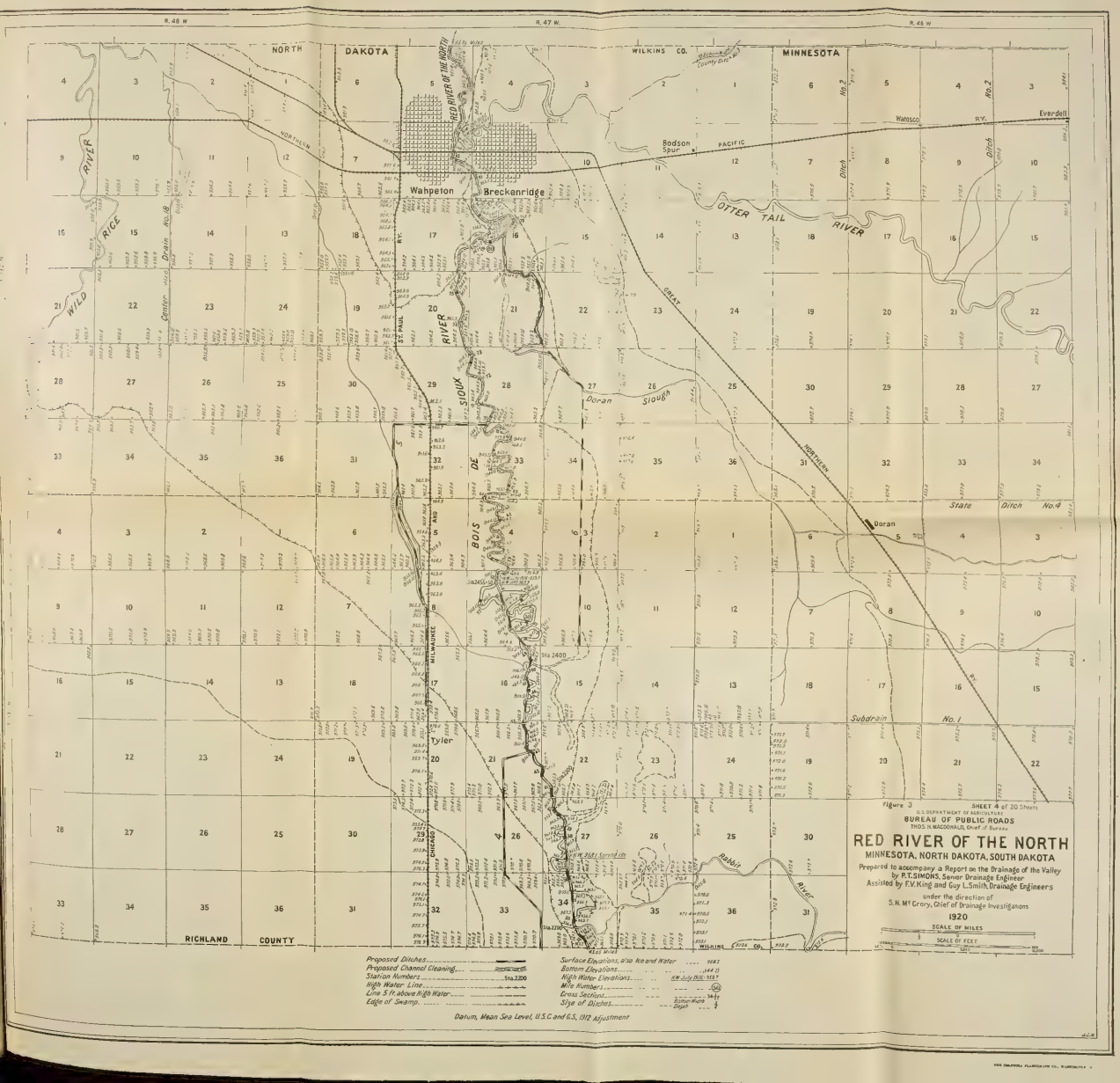

Figure 3 SHEET 4 of 20 Sheets

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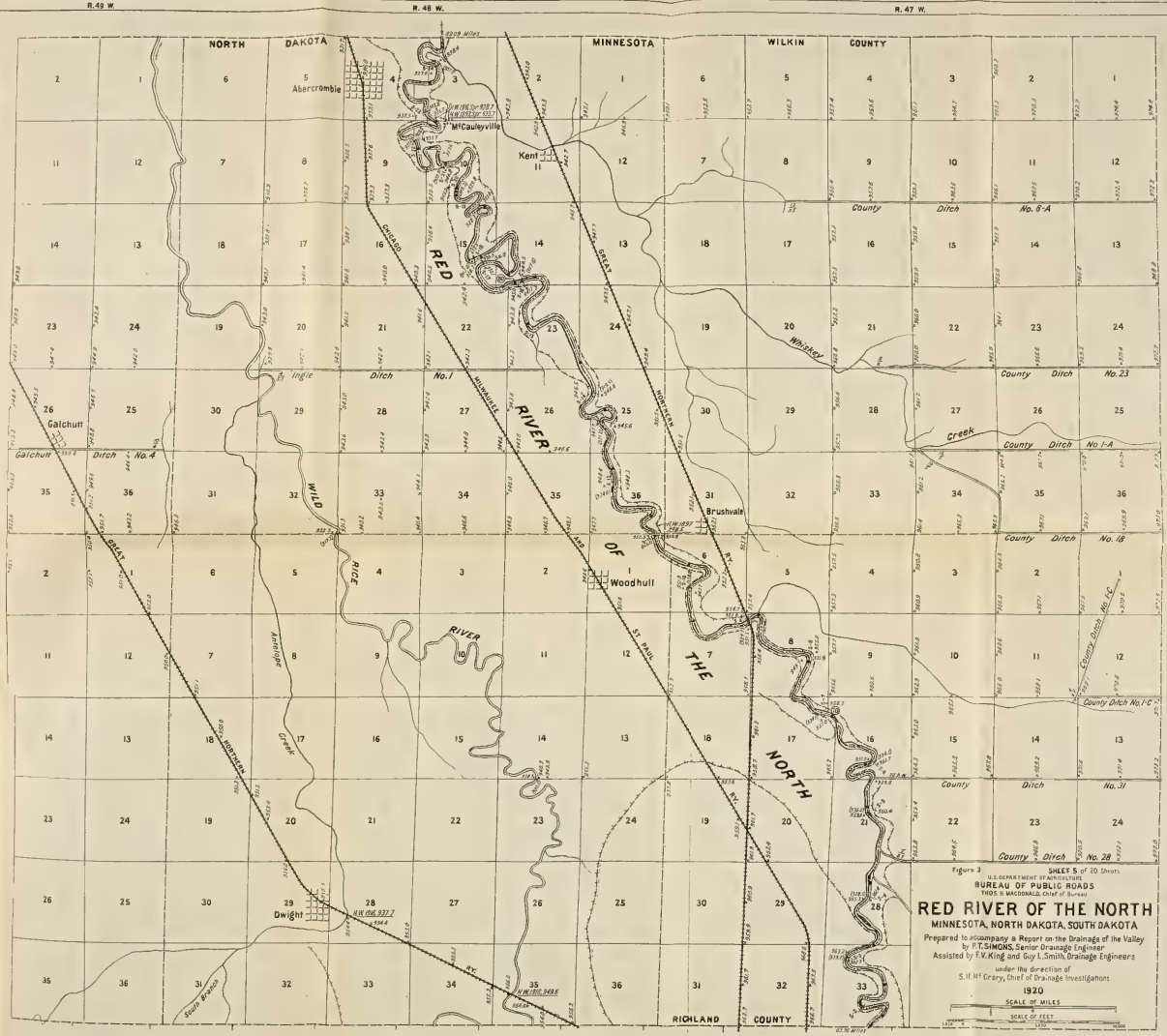

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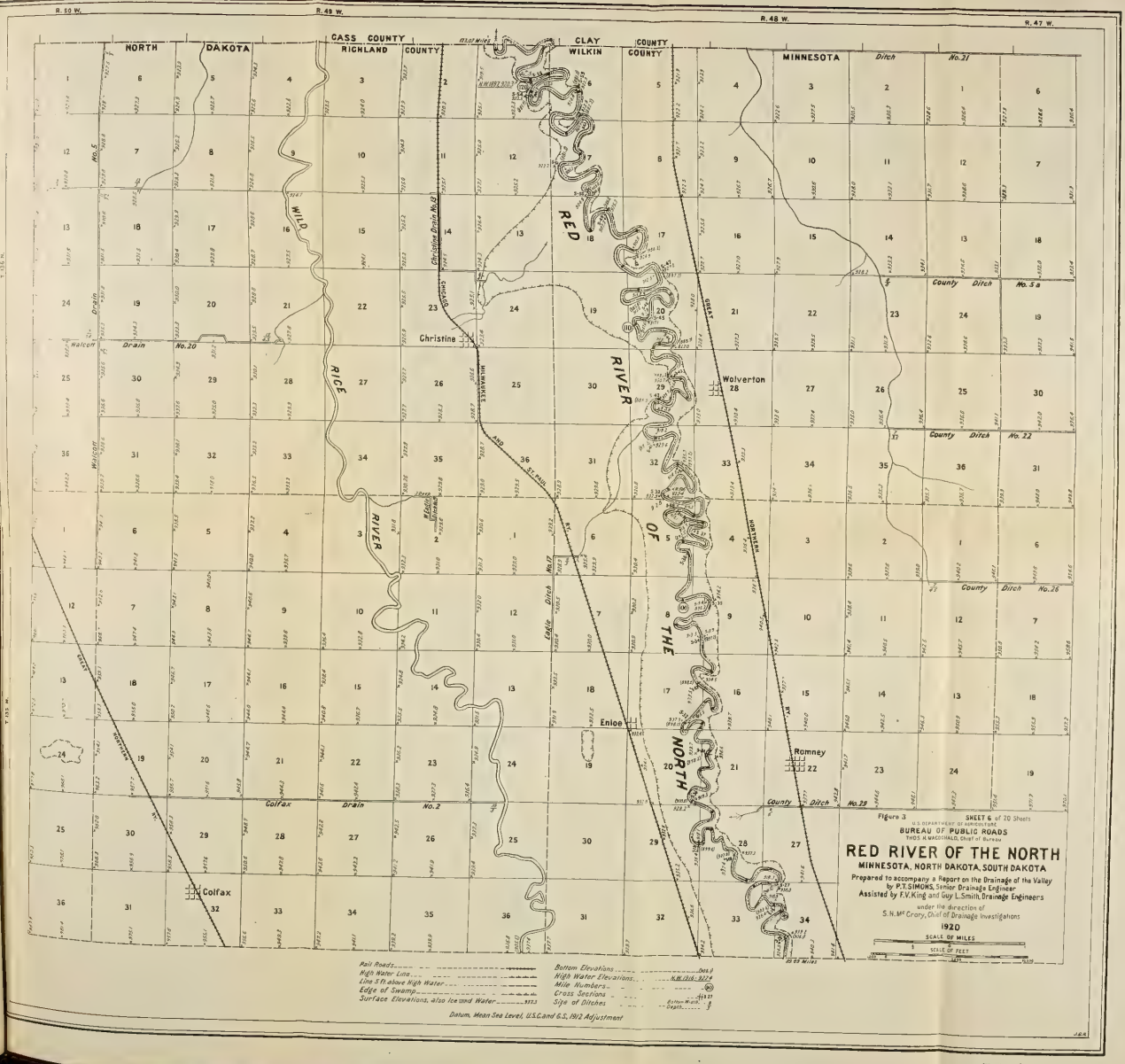
R. 50 W.
R. 49 W.
R. 48 W.
R. 47 W.
T. 136 N.
T. 135 N.
NORTH DAKOTA
CASS COUNTY
RICHLAND COUNTY
CLAY COUNTY
WILKIN COUNTY
MINNESOTA
Ditch No. 21
County Ditch No. 5a
County Ditch No. 22
County Ditch No. 26
County Ditch No. 29
Colfax Drain No. 2
Walcott Drain No. 20
Christine Drain No. 13
Eagle Ditch No. 17
WILD RICE RIVER
RED RIVER OF THE NORTH
CHICAGO MILWAUKEE AND ST. PAUL RY.
GREAT NORTHERN RY.
Christine
Wolverton
Enloe
Romney
Colfax
Figure 3
SHEET 6 of 20 Sheets
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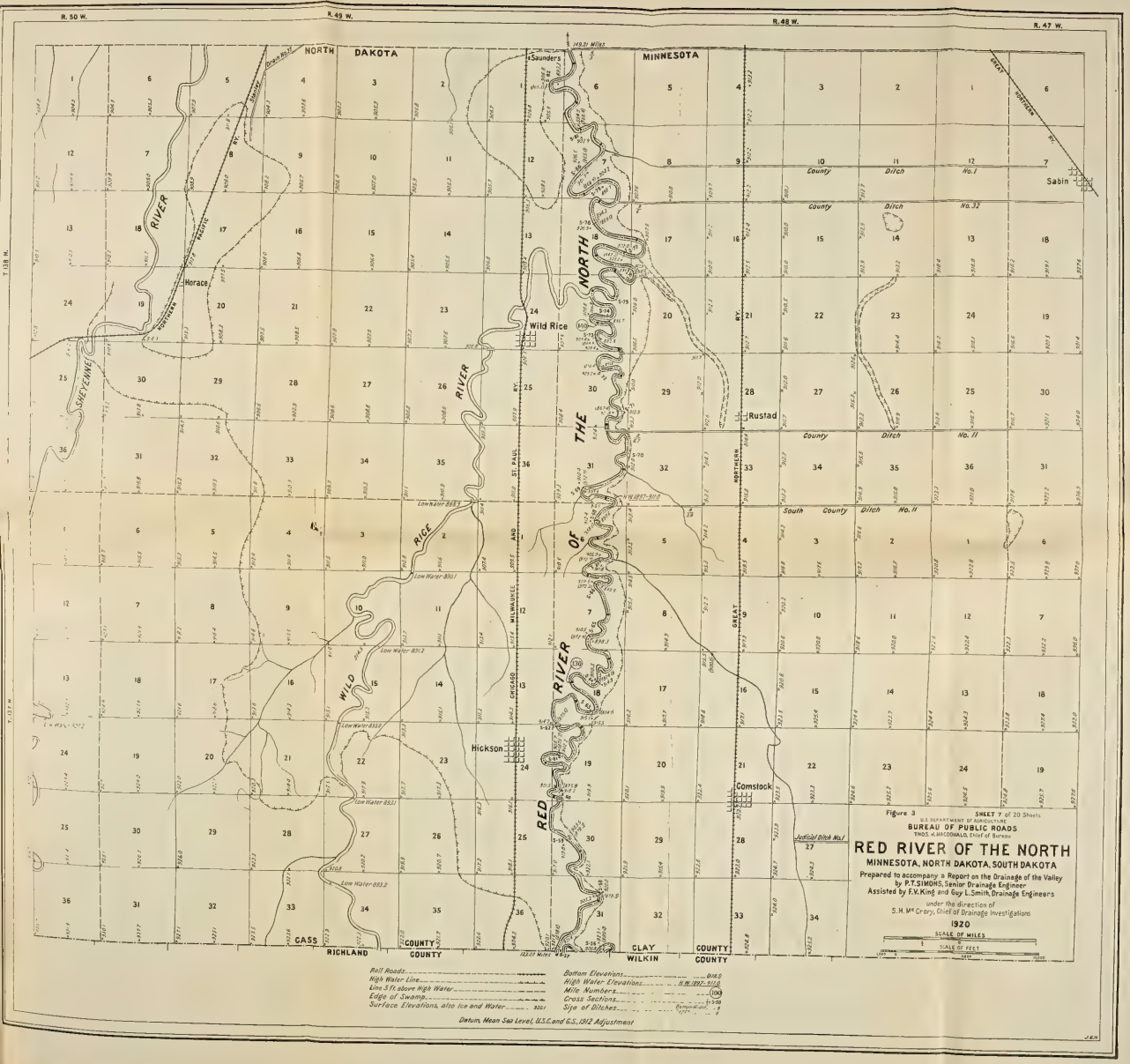
SCALE OF MILES
SCALE OF FEET
Rail Roads
High Water Line
Line 5 ft. above High Water
Edge of Swamp
Surface Elevations, also Ice and Water
Bottom Elevations
High Water Elevations
Mile Numbers
Cross Sections
Size of Ditches
Datum, Mean Sea Level, U.S.C. and G.S., 1912 Adjustment


R. 50 W.
R. 49 W.
R. 48 W.
R. 47 W.
T. 138 N.
T. 137 N.
NORTH DAKOTA
MINNESOTA
Saunders
Sabin
Horace
Wild Rice
Rustad
Hickson
Comstock
SHEYENNE RIVER
WILD RICE RIVER
RED RIVER OF THE NORTH
NORTHERN PACIFIC RY.
GREAT NORTHERN RY.
CHICAGO MILWAUKEE AND ST. PAUL RY.
CASS COUNTY
RICHLAND COUNTY
CLAY COUNTY
WILKIN COUNTY
Low Water 888.3
Low Water 890.1
Low Water 891.2
Low Water 893.0
Low Water 893.1
Low Water 893.2
Judicial Ditch No. 1
County Ditch No. 1
County Ditch No. 32
County Ditch No. 11
South County Ditch No. 11
149.21 Miles
122.07 Miles
Figure 3
SHEET 7 of 20 Sheets
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SCALE OF FEET
Rail Roads
High Water Line
Line 5 ft. above High Water
Edge of Swamp
Surface Elevations, also Ice and Water 920.1
Bottom Elevations 918.0
High Water Elevations H.W. 1897-911.0
Mile Numbers 100
Cross Sections 5-50
Size of Ditches
Datum, Mean Sea Level, U.S.C. and G.S., 1912 Adjustment

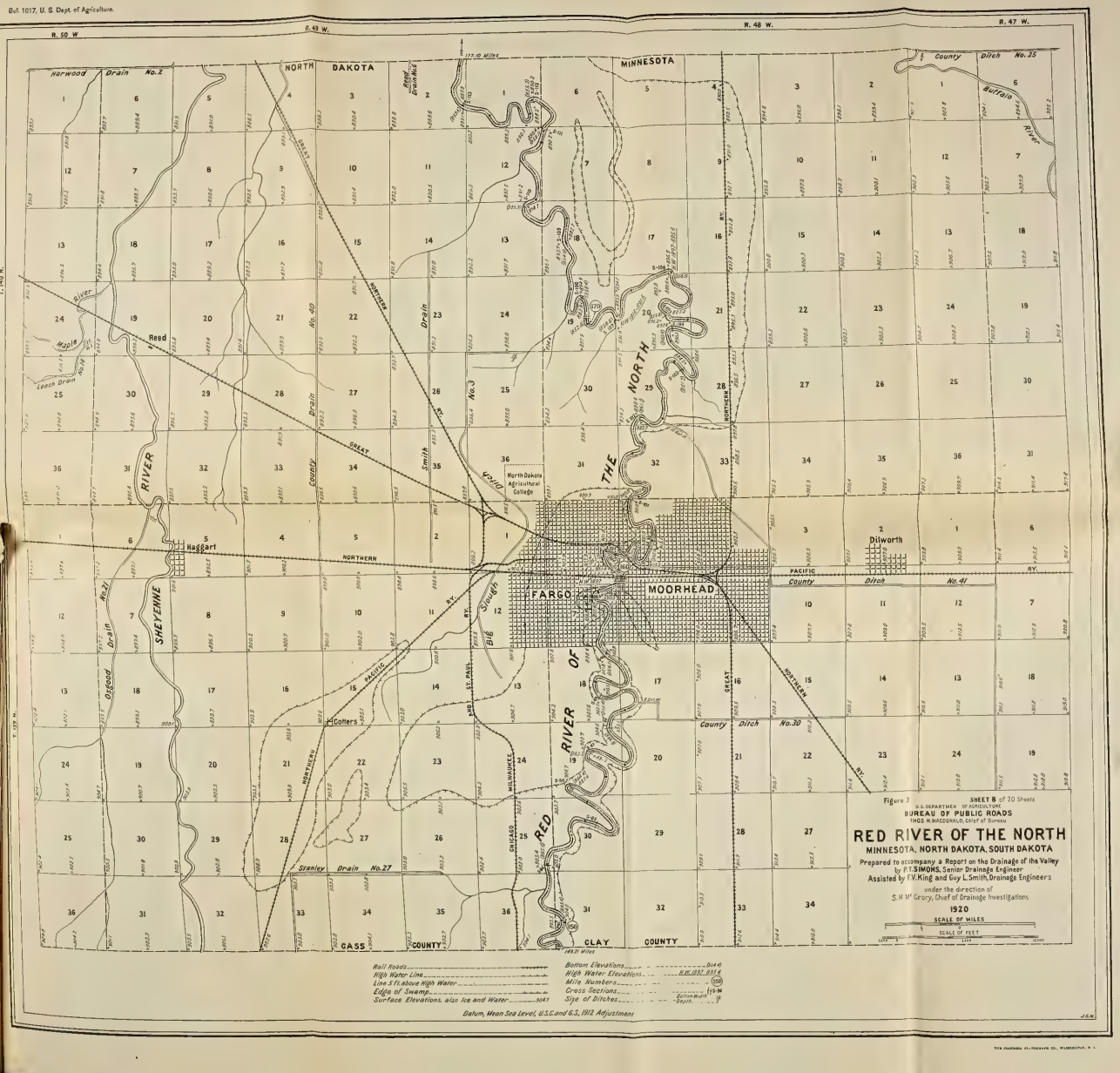

Figure 3 SHEET 8 of 20 Sheets

U.S. DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS
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S. H. McCrory, Chief of Drainage Investigations

1920

SCALE OF MILES

SCALE OF FEET

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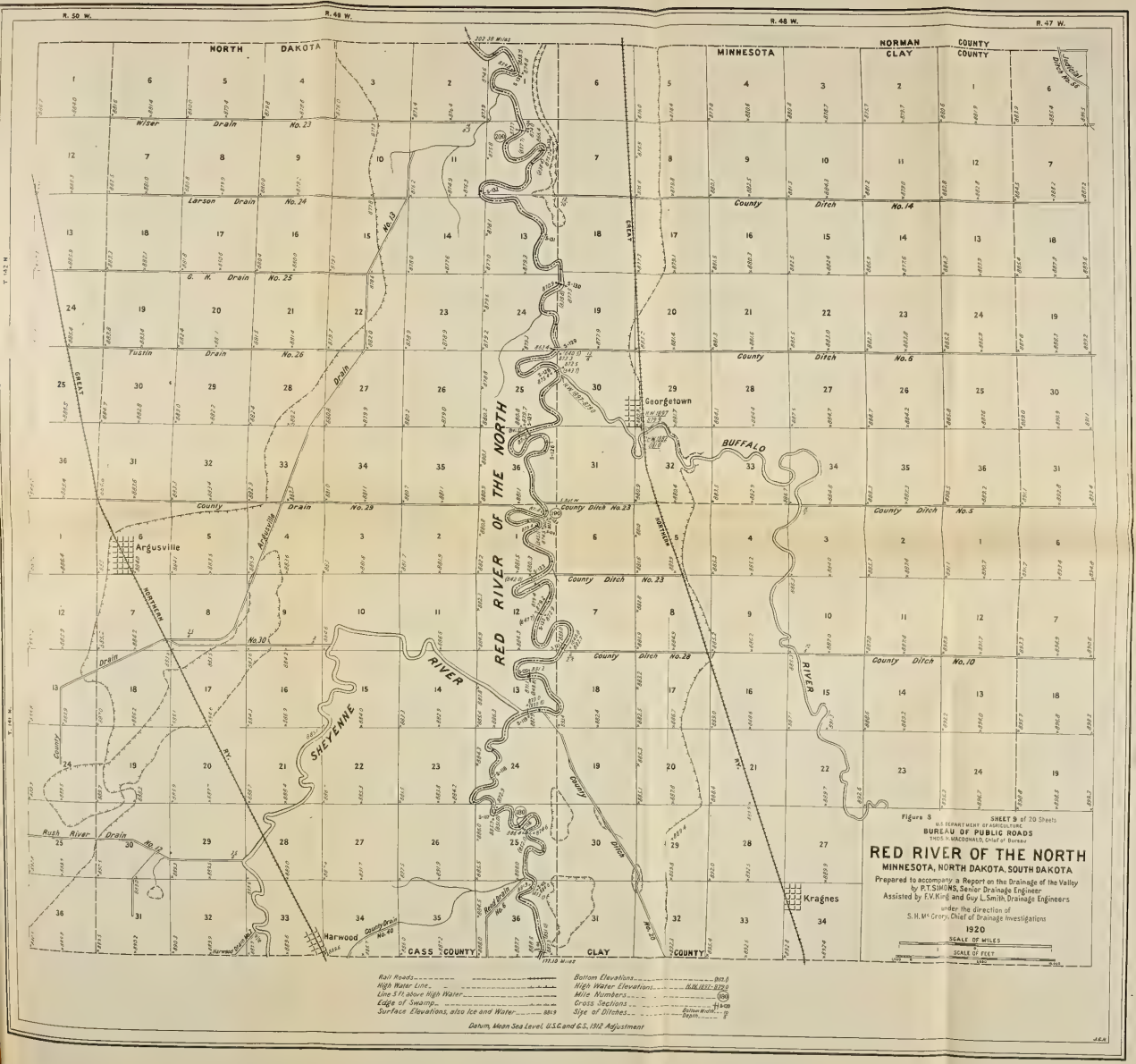

Figure 8

SHEET 9 of 20 Sheets

U.S. DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS
THOS. H. MACDONALD, Chief of Bureau

RED RIVER OF THE NORTH

MINNESOTA, NORTH DAKOTA, SOUTH DAKOTA

Prepared to accompany a Report on the Drainage of the Valley by P.T. SIMONS, Senior Drainage Engineer
Assisted by F.V. King and Guy L. Smith, Drainage Engineers
under the direction of
S. H. McCrory, Chief of Drainage Investigations

1920

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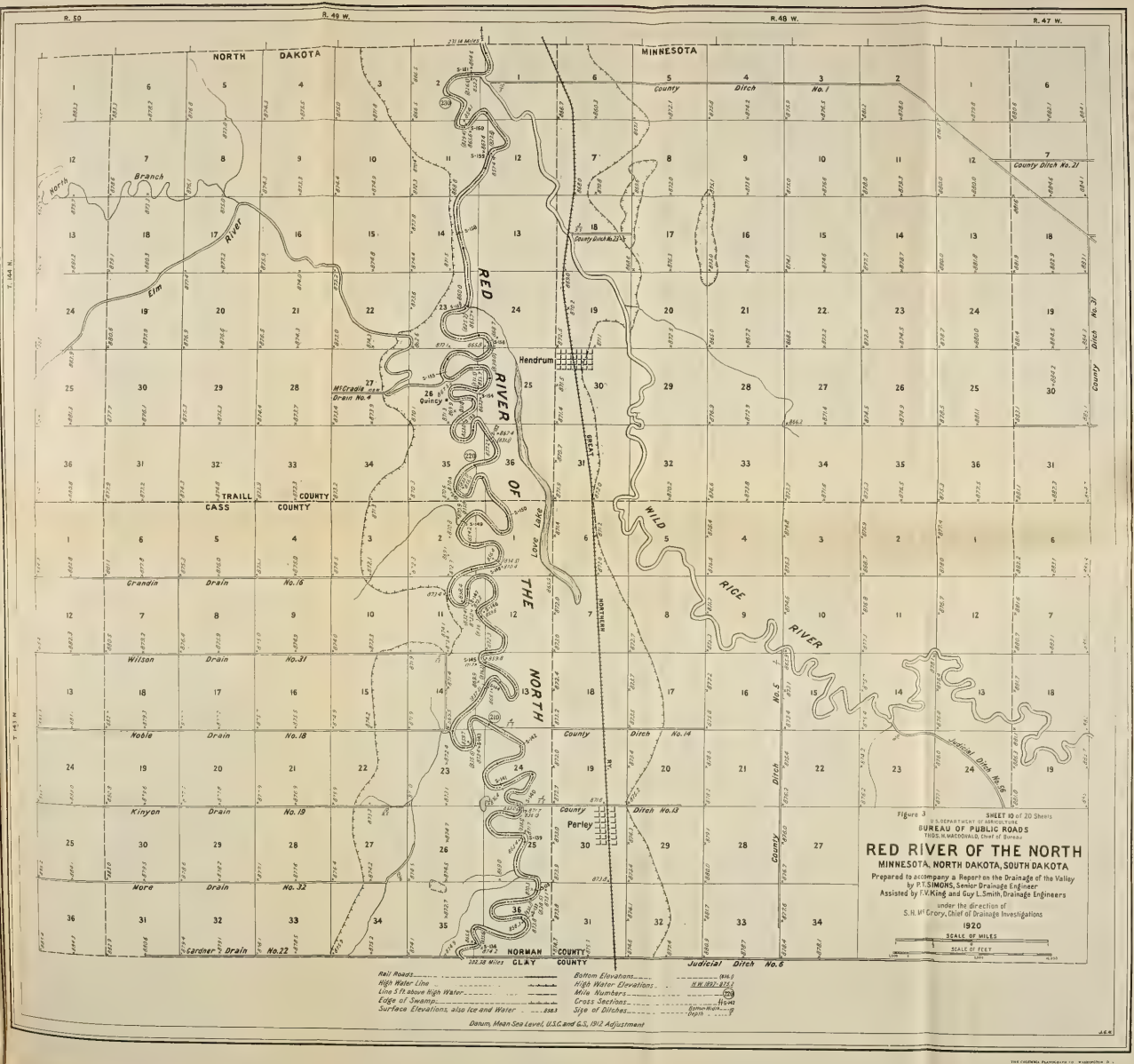

Figure 3 SHEET 10 of 20 Sheets

U. S. DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS
THOS. H. MACDONALD, Chief of Bureau

RED RIVER OF THE NORTH

MINNESOTA, NORTH DAKOTA, SOUTH DAKOTA

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by P. T. SIMONS, Senior Drainage Engineer
Assisted by F. V. King and Guy L. Smith, Drainage Engineers
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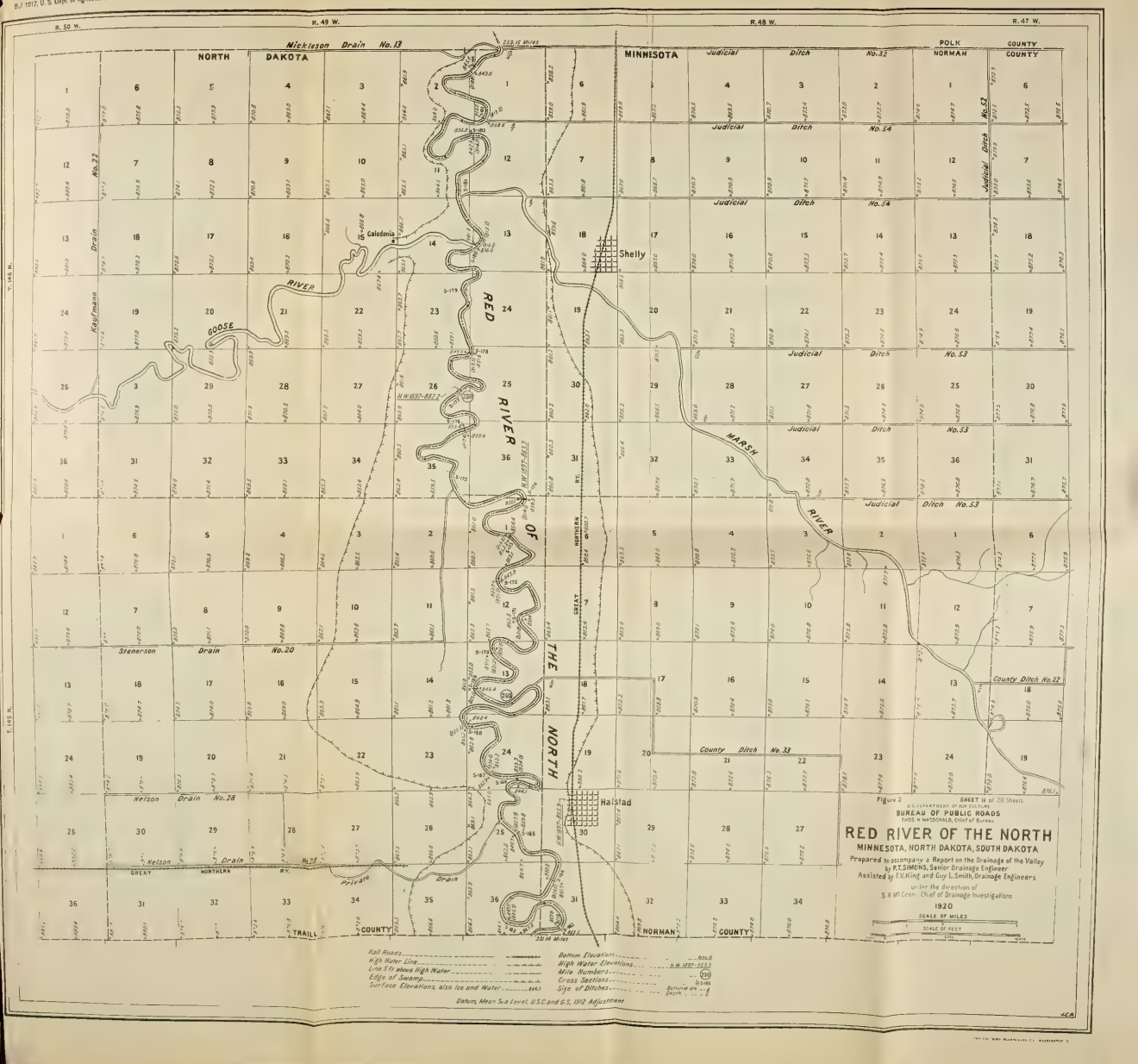
THE COLUMBIA PLANOGRAPH CO. WASHINGTON D. C.


R. 50 W.
R. 49 W.
R. 48 W.
R. 47 W.
T. 145 N.
T. 144 N.
NORTH DAKOTA
MINNESOTA
POLK COUNTY
NORMAN COUNTY
TRAILL COUNTY
Mickelson Drain No. 13
Kaufmann Drain No. 22
Stenerson Drain No. 20
Nelson Drain No. 28
Judicial Ditch No. 32
Judicial Ditch No. 54
Judicial Ditch No. 53
Judicial Ditch No. 52
County Ditch No. 22
County Ditch No. 33
Private Drain
GOOSE RIVER
MARSH RIVER
RED RIVER OF THE NORTH
GREAT NORTHERN RY.
Caledonia
Shelly
Halstad
255.15 Miles
20.14 Miles
H.W. 1897-852.2
Rail Roads
High Water Line
Line 5 ft above High Water
Edge of Swamp
Surface Elevations, also Ice and Water
Bottom Elevations
High Water Elevations
Mile Numbers
Cross Sections
Size of Ditches
Datum, Mean Sea Level, U.S.C. and G.S. 1912 Adjustment
Figure 3
SHEET 11 of 20 Sheets
U.S. DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS
THOS. H. MACDONALD, Chief of Bureau
RED RIVER OF THE NORTH
MINNESOTA, NORTH DAKOTA, SOUTH DAKOTA
Prepared to accompany a Report on the Drainage of the Valley
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SCALE OF MILES
SCALE OF FEET

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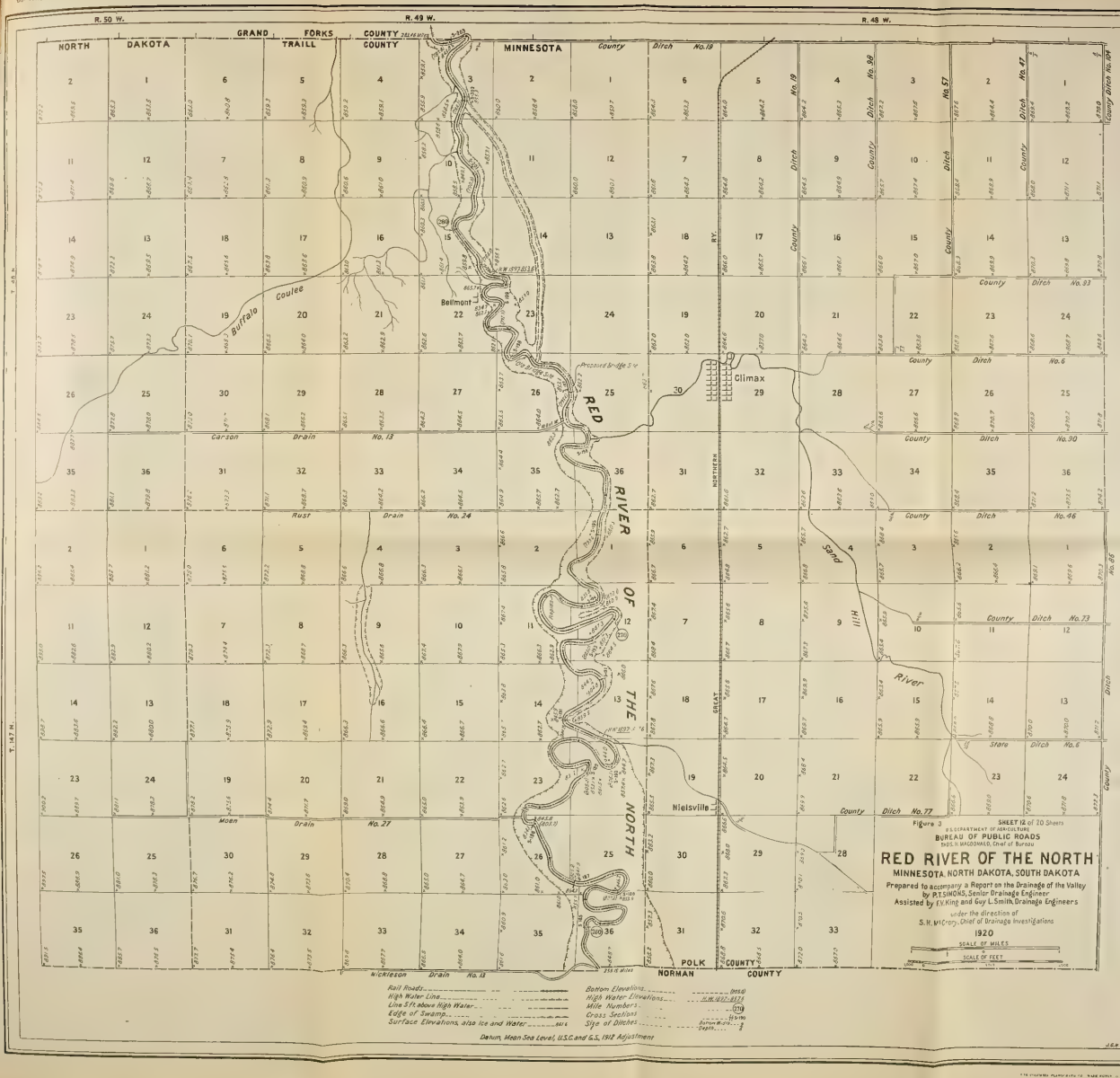

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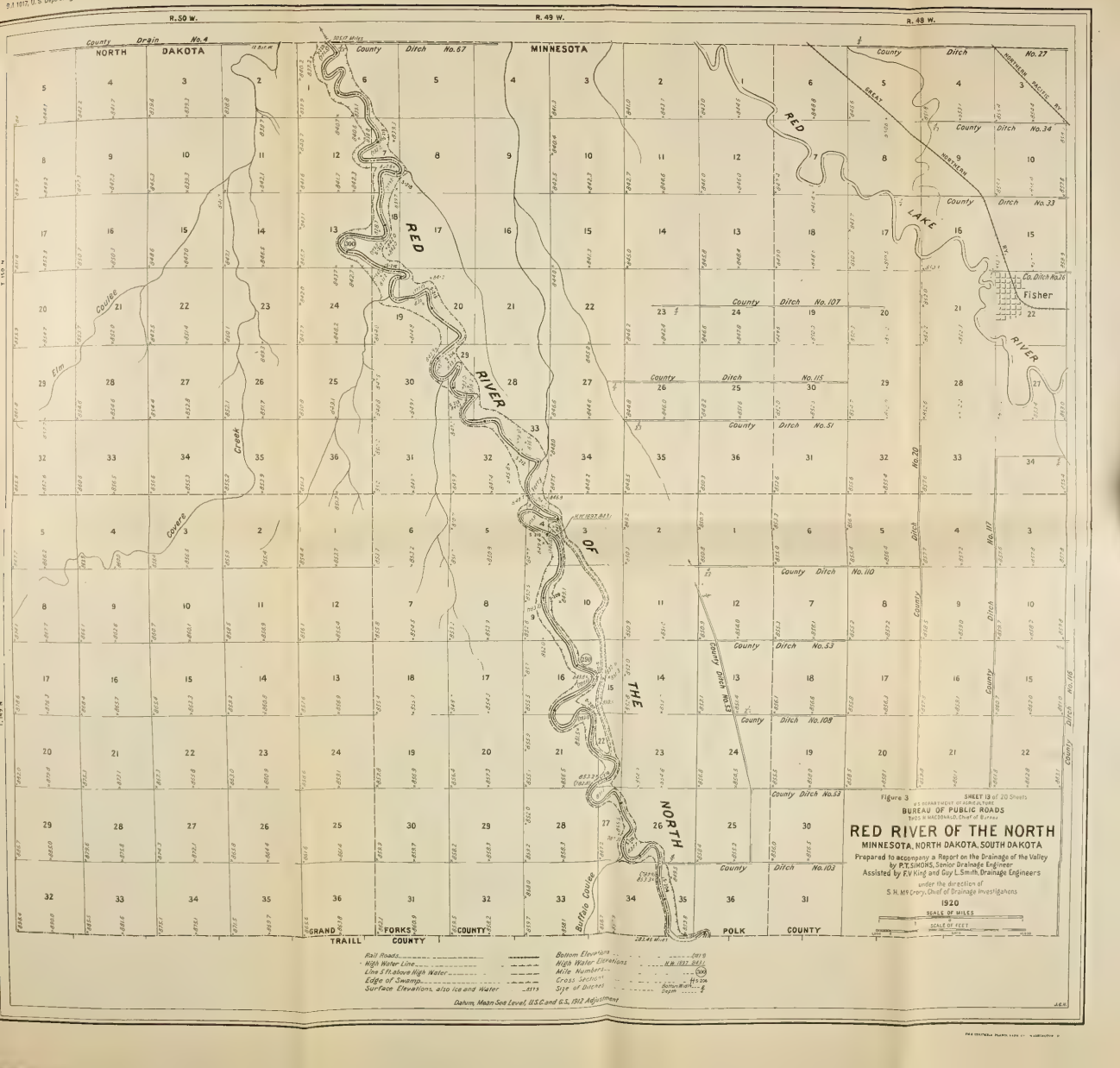

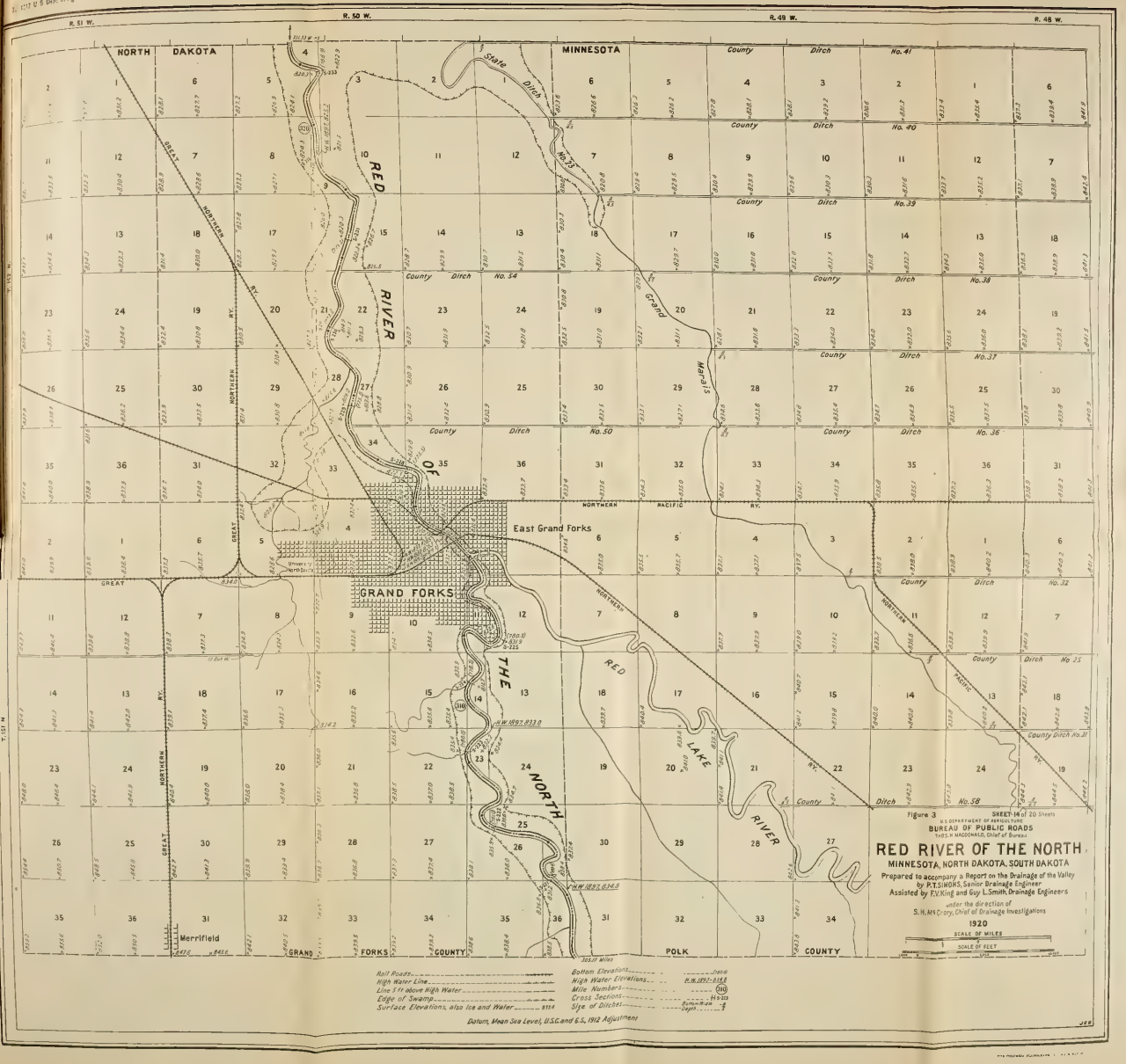

U S Dept. of Agriculture
R. 51 W.
R. 50 W.
R. 49 W.
R. 48 W.
T. 152 N.
T. 151 N.
NORTH DAKOTA
MINNESOTA
RED RIVER OF THE NORTH
GRAND FORKS
East Grand Forks
Merrifield
GRAND FORKS COUNTY
POLK COUNTY
RED LAKE RIVER
Grand Marais
State Ditch No. 73
County Ditch No. 41
County Ditch No. 40
County Ditch No. 39
County Ditch No. 54
County Ditch No. 38
County Ditch No. 37
County Ditch No. 50
County Ditch No. 36
County Ditch No. 32
County Ditch No. 25
County Ditch No. 31
County Ditch No. 58
GREAT NORTHERN RY.
NORTHERN PACIFIC RY.
Figure 3
SHEET 14 of 20 Sheets
U.S. DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS
THOS. H. MACDONALD, Chief of Bureau
RED RIVER OF THE NORTH
MINNESOTA, NORTH DAKOTA, SOUTH DAKOTA
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1920
SCALE OF MILES
SCALE OF FEET
Rail Roads
High Water Line
Line 5 ft above High Water
Edge of Swamp
Surface Elevations, also Ice and Water
Bottom Elevations
High Water Elevations
Mile Numbers
Cross Sections
Size of Ditches
Datum, Mean Sea Level, U.S.C. and G.S., 1912 Adjustment

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Figure 3

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U.S. DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS
THOS. H. MACDONALD, Chief of Bureau

RED RIVER OF THE NORTH

MINNESOTA, NORTH DAKOTA, SOUTH DAKOTA

Prepared to accompany a Report on the Drainage of the Valley by P. T. SIMONS, Senior Drainage Engineer
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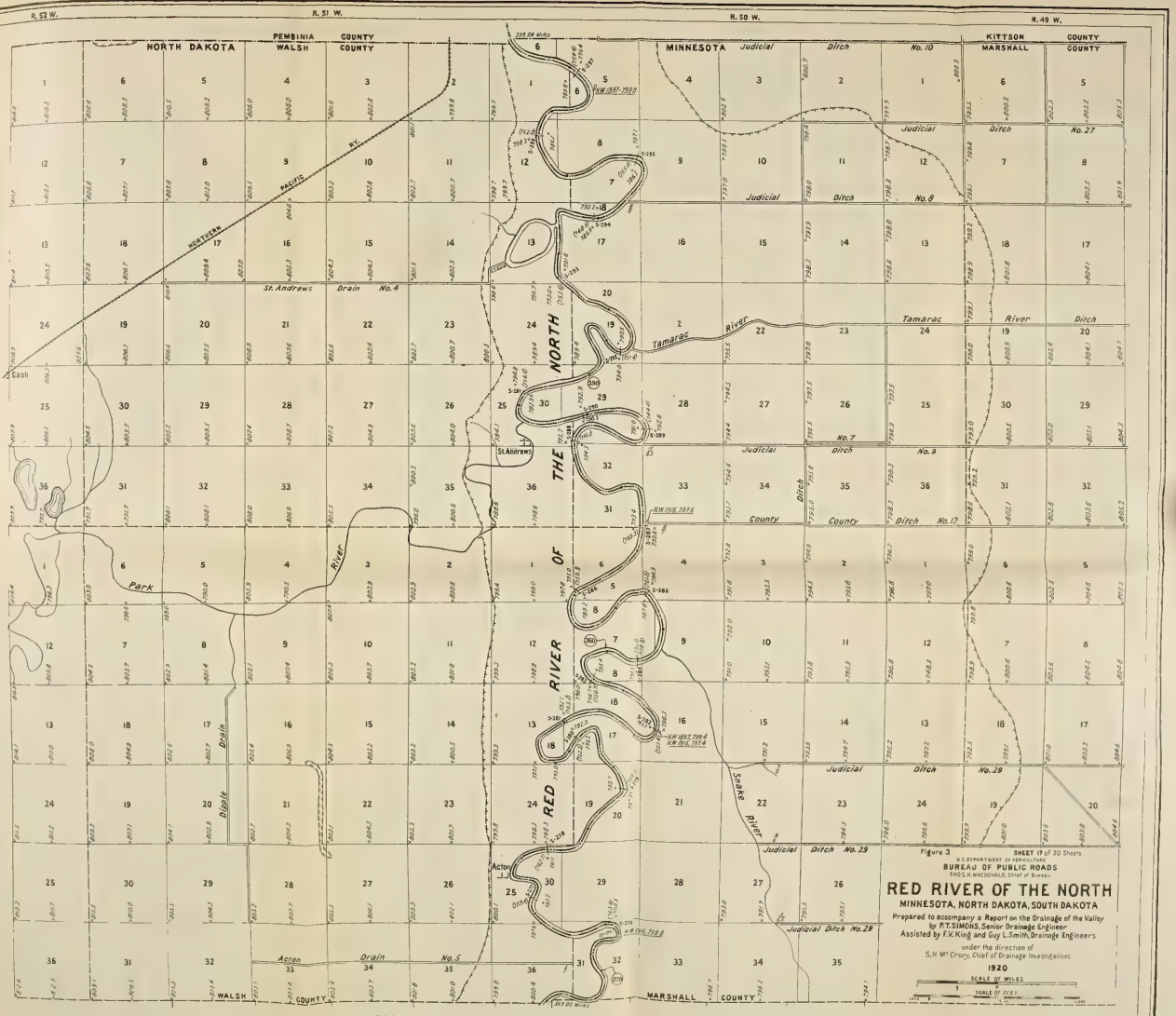
1920

SCALE OF MILES
SCALE OF FEET

THE INGERSOLL PLATE CO. WASHINGTON D. C.

Bul. 1017, U.S. Dept. of Agriculture



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B.J 1017, U. S. Dept. of Agriculture.

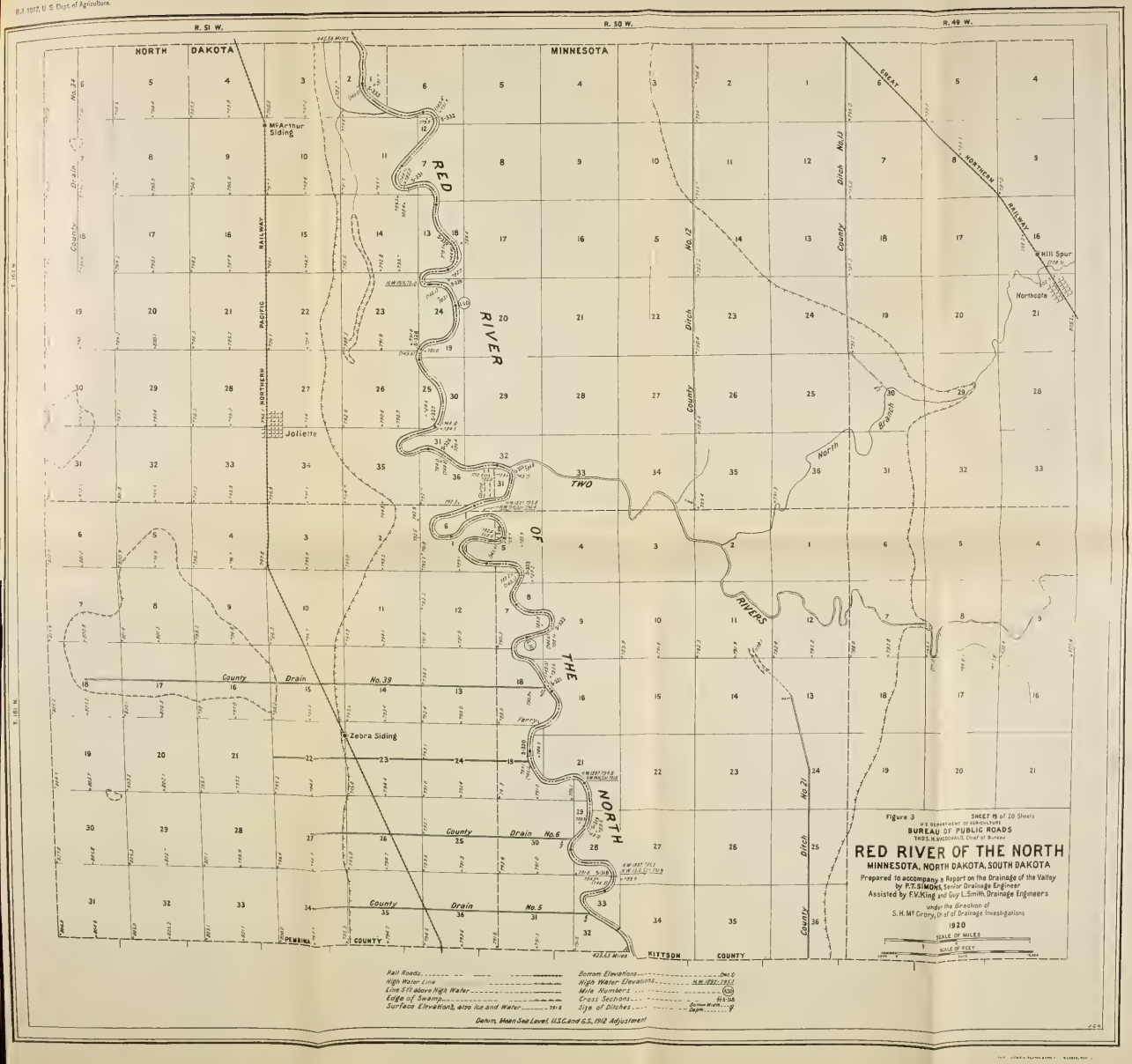

Figure 3 SHEET 19 of 20 Sheets

U.S. DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS
THOS. H. MACDONALD, Chief of Bureau

RED RIVER OF THE NORTH

MINNESOTA, NORTH DAKOTA, SOUTH DAKOTA

Prepared to accompany a Report on the Drainage of the Valley by P.T. SIMONS, Senior Drainage Engineer
Assisted by F.V. King and Guy L. Smith, Drainage Engineers
under the direction of
S.H. McCrory, Chief of Drainage Investigations

1920

SCALE OF MILES
SCALE OF FEET

B-1 1017, U. S. Dept. of Agriculture

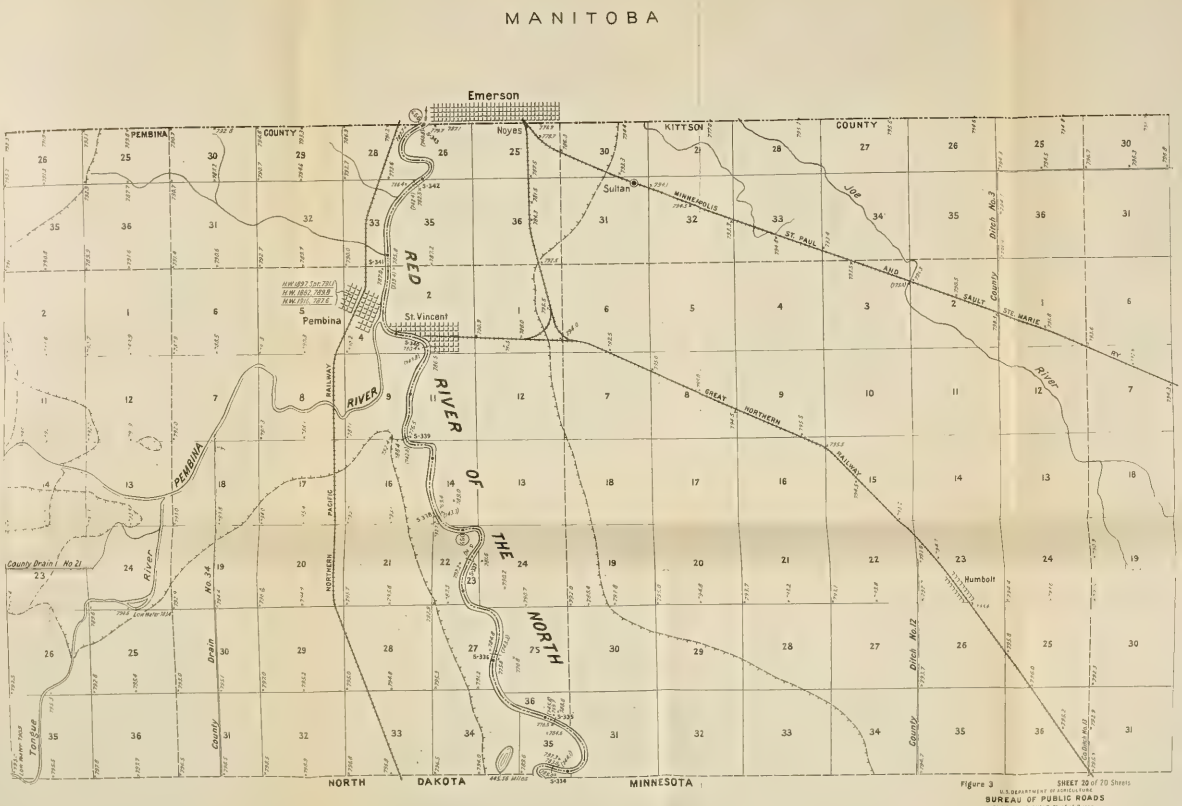

Figure 3 SHEET 20 of 70 Sheets

U.S. DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS
THOS. H. MACDONALD, Chief of Bureau

RED RIVER OF THE NORTH

MINNESOTA, NORTH DAKOTA, SOUTH DAKOTA

Prepared to accompany a Report on the Drainage of the Valley
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1920

SCALE OF MILES
SCALE OF FEET

Rail Roads
High Water Line
Line 5 ft. above High Water
Edge of Swamp
Surface Elevations, also Ice and Water 793.7

Bottom Elevations 745.0
High Water Elevations H.W. 1897-791.1
Mile Numbers 150
Cross Sections S-335
Size of Ditches Bottom Width Depth

Datum, Mean Sea Level, U.S.C. and G.S., 1912 Adjustment

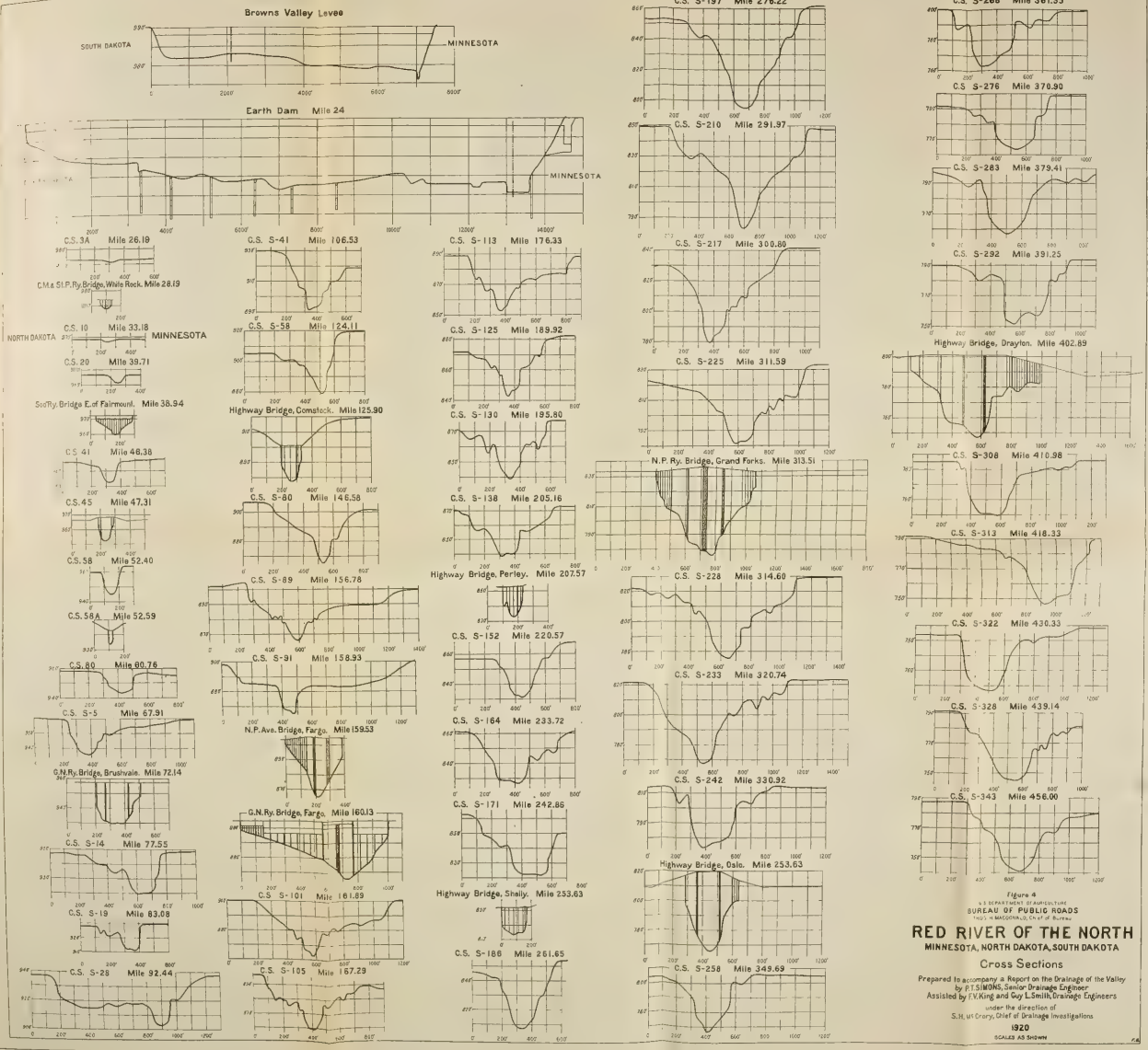

Figure 4

U.S. DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS
THOS. H. MACDONALD, Chief of Bureau

RED RIVER OF THE NORTH

MINNESOTA, NORTH DAKOTA, SOUTH DAKOTA

Cross Sections

Prepared to accompany a Report on the Drainage of the Valley
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SCALES AS SHOWN

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were tabulated or plotted as curves showing various relations. Run-off records were studied and the problem of the relation between precipitation and run-off was approached from various angles in an effort to reach reliable conclusions as to maximum rates of flow which may occur in the different parts of the Red River, the coincidence of heavy flow in the various tributaries, and the probable time intervals between damaging flood stages.

DRAINAGE.

The drainage situation over the watershed was studied in considerable detail. The flat land along both sides of the main watercourse was considered separately from the higher, backlying areas, as its drainage is more intimately related to the conditions of flow in the main channel. Areas affected by present drainage of these flats were determined and estimates made as to probable future drainage and its effects.

Considerable areas of land along the Bois de Sioux River lie only slightly higher than the normal water surface in that stream. Under high-water conditions these lands are submerged and form a part of the bed of Lake Traverse. At all times these areas are marshy and unfit for agricultural purposes. Estimates were made as to the amount of such land reclaimable and the extent of improvement possible. Details for the complete drainage of the areas were not worked out, but plans for the main channel improvement of the Bois de Sioux include the layout of main outlet ditches necessary for the disposal of overflow water and of the flow from future local drains.

The general conditions of drainage systems in all parts of the watershed were investigated. The question of tile drainage, its probable development and general effect on the outlet channels, was also considered.

FLOODS.

In studying the flood situation the main object was to determine as accurately as possible the extent of damaging flow with corresponding river stages, the probable frequency and magnitude of future floods, and the maximum flow that may be expected. The studies of precipitation, run-off, and effects of drainage were made mainly for this purpose. Information concerning floods from whatever source was considered and given such weight as its importance and reliability seemed to warrant.

MEASURES FOR RELIEF.

Relief measures were considered under two heads, drainage and flood relief. The question of draining the wet lands along the Bois de Sioux River was taken up along with that of the detention reser-

voir for the control of run-off from the Lake Traverse watershed, as together they form a single interstate project for combined drainage and flood prevention for that territory. The improvement of the Red River channel is an interstate proposition and the increase of its capacity is a measure for the prevention of floods. When proper provision has been made for the removal of the water that may come to the channel from the several States, the drainage of the land along its course becomes a matter of locally controlled projects, and is so considered in this report.

The Bois de Sioux-Red River channel was studied in detail with respect to size, course, slope, and condition as to obstruction. Various methods of increasing the capacity were considered and conclusions reached as to their effectiveness and practicability. Widening and deepening of the channel; cut-offs; removal of brush, trees, and débris; relocation of bridges; and changes in points of entry of tributary streams by means of stream diversion and artificial embankment—these were all considered in some location or other, wherever applicable.

As the study of flood flow and channel capacities made it apparent that complete relief from flood conditions can not be economically secured through channel improvement alone, the possibility of reducing high-water stages by means of temporary storage in the upper reaches of the streams was investigated. The only locations which seem to offer practicable opportunities in this respect are the Red Lake and Lake Traverse regions. The former has been investigated by engineers of the War Department, which has reported favorably upon the proposed improvement.[3] An abstract of that report appears in another part of this report. The effect of that project upon Red River conditions has been considered in the present investigation.

A thorough field study was made of the Lake Traverse region to determine the most advantageous location for a reservoir and its efficiency under extreme conditions of run-off. Storage capacities for various stages were computed and tentative plans were prepared for the necessary controlling works. The results of such storage in the case of the territory immediately benefited, and its effect upon the conditions of flow in the Red River, were considered.

The plans for recommended improvements were worked up with the view of securing the maximum benefits at the least cost and an equitable distribution of these two factors among all concerned.

RUN-OFF.

Run-off is that portion of the precipitation which, falling upon a watershed, flows over or through the earth to a watercourse and

[3] Document No. 61, House of Representatives, 66th Cong., 1st sess.

thence out of the watershed. Precipitation is the source of run-off, but many different factors affect the amount and rate of run-off from a given watershed. A portion of the water is absorbed by the soil; some of this passes through the soil into drainage channels. A part is evaporated from the soil or is transpired by plants and trees or is evaporated from the surface of the soil. A small amount sinks deep into the ground, and the remainder passes over the surface of the ground to a watercourse and through it out of the watershed. The rate and amount of run-off from a watershed are affected principally by the amount and distribution of the precipitation and its form—whether rain or snow.

After precipitation the principal factors which affect the rate of run-off from a watershed are topography, size and shape of the watershed, prevailing temperature, character of vegetation on the watershed, and artificial drainage. In addition to these and somewhat dependent upon them are evaporation, transpiration of plants, absorption by the soil, and storage, all of which tend to regulate the amount of water reaching drainage channels. The effect of these several factors upon the amount and rate of run-off is not constant but is continually changing. It is exceedingly difficult, if not impossible, to measure the effect of the various factors upon the run-off, and in the absence of measurements from a given watershed the determination of the probable rate of run-off becomes a complex problem.

The best bases for calculating future run-off are measurements of stream flow extending over a long period of time for the particular watershed under consideration. If such records are available, the amount and rate of run-off can be estimated closely unless the physical features which affect run-off from the watershed are materially changed. If complete data for a long period are not available, then records for a shorter time on the watershed under consideration, or on more or less similar watersheds, are most essential. For the watershed of the Red River, and especially for those of its tributaries, the run-off records are meager because settlement and development in the valley are only comparatively recent.

Daily records of the river stage at Grand Forks, from which the run-off at that point can be computed, are available as far back as 1882. From 1882 to 1901 the gauge readings were recorded by the Corps of Engineers, United States Army, and from 1902 to the present time by the United States Geological Survey. Similar records are available for the Red River at Fargo from 1902 to the present time, as are also records for 12 stations on tributary streams for periods of from 1 to 17 years, since 1901. The daily flow of the river at Emerson, Manitoba, just north of the international boundary,

has been recorded since May, 1912, by the Manitoba Hydrometric Survey. A list of these available records of stream discharge is given in Table 3.

TABLE 3.—*Maximum stream discharges on Red River watershed.*

Stream.	Station.	Watershed area, square miles.	Period.	Maximum discharge.		Authority.
				Rate.	Date.	
				Sec.-ft.		
Mustinka River	Wheaton	756	1917–1919	2,240	Apr. 1, 1917	U. S. Geological Survey and U. S. Department of Agriculture.
Bois de Sioux River	Fairmount	1,480	1919–1920	255	Mar. 24, 1920	U. S. Department of Agriculture.
Otter Tail River	Fergus Falls	1,300	1900–1917	1,080	June 13, 1904	U. S. Engineers and U. S. Geological Survey.
North Dakota Wild Rice River.	Mouth, Wild Rice.	2,210	1919–1920	1,779	Mar. 24, 1920	U. S. Department of Agriculture.
Red River	Fargo-Moorhead	6,435	1902–1919	7,720	July 11, 1916	Do.
Sheyenne River	Valley City	4,185	1919	2,750	Apr. 18, 1919	Do.
Do	Haggart	5,600	1902–1907, 1919	2,220	Apr. 28, 1919	U.S. Geological Survey and U. S. Department of Agriculture.
Minnesota Wild Rice River.	Twin Valley	835	1909–1917	9,120	July 22, 1909	U. S. Geological Survey.
Thief River	Thief River Falls	1,080	1909–1917	4,100	Apr. 23, 1916	Do.
Red Lake River and Thief River.	do	3,600		7,600	July 3, 1919	
Clearwater River	Red Lake Falls	1,330	1909–1919	6,700	do	Do.
Red Lake River	Crookston	5,320	1901–1919	14,400	Apr. 17, 1916	Do.
Red River	Grand Forks	25,755	1882–1919	43,000	Apr. 10, 1897	U. S. Engineers and U. S. Geological Survey.
Two Rivers	Hallock	635	1911–1914	1,200	Apr. 13, 1913	U. S. Geological Survey.
Pembina River	Neche	3,320	1903–1915, 1919	3,870	May 2, 1904	Do.
Red River	Emerson, Manitoba	35,895	1912–1919	46,180	Apr. 24, 1916	Manitoba Hydrometric Survey.

As indicated in the table, the Geological Survey has made most of the stream-flow measurements. This work was done in connection with the determination of the water supply of the United States.[4]

A limited number of measurements of stream flow were made by the Department of Agriculture in connection with the survey of Red River during 1919 and 1920. Of these the principal measurements were: The Sheyenne River at Valley City and at Haggart, N. Dak., during March and April, 1919; the Wild Rice River at Wild Rice, N. Dak., March, 1920; and the Bois de Sioux River at Fairmount, N. Dak., March, 1920. These records are valuable because quite high stages occurred during the periods mentioned and because no previous gagings had been made at three of the stations.

The records of stream flow at Grand Forks are shown in Table 4. The quantities of run-off were computed from daily gage readings except for January, February, March, and December, 1882, to 1900, for which periods no gage records are available. For those months

[4] U. S. Geol. Survey, Water Supply Papers 405, 435, 455, etc.

estimates were made from records for corresponding months from 1901 to 1919. The estimates of annual run-off are only slightly affected by the December-March figures, so the annual quantities for the entire period of 38 years are considered to be reasonably accurate.

TABLE 4.—*Run-off (in billions of cubic feet) from the Red River watershed above Grand Forks, N. Dak.*

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Yearly totals.
1882	2.46	1.96	4.28	62.48	47.43	20.89	17.03	10.91	6.95	6.94	5.24	3.06	189.63
1883	2.46	1.96	4.28	34.00	46.12	15.13	8.75	5.78	4.16	4.09	4.25	3.06	134.04
1884	2.46	1.96	4.28	27.28	14.42	11.66	7.36	4.63	7.36	10.40	8.44	3.06	103.31
1885	2.46	1.96	4.28	17.46	13.81	13.89	17.52	14.92	7.87	5.98	5.29	3.06	108.50
1886	2.46	1.96	4.28	18.48	17.64	8.08	5.01	2.39	1.61	1.90	2.60	3.06	69.47
1887	2.46	1.96	4.28	9.81	5.74	4.02	3.69	3.73	2.81	2.12	1.82	3.06	45.50
1888	2.46	1.96	4.28	26.35	13.63	23.38	14.20	6.82	3.12	2.88	2.98	3.06	105.12
1889	2.46	1.96	4.28	6.63	4.04	2.27	1.90	1.53	1.39	1.69	1.53	3.06	32.74
1890	2.46	1.96	4.28	6.17	3.26	4.05	3.57	1.67	2.13	2.61	2.61	3.06	37.83
1891	2.46	1.96	4.28	11.25	4.98	3.90	4.37	3.85	2.46	4.07	4.07	3.06	50.71
1892	2.46	1.96	4.28	47.78	24.60	20.13	10.65	4.45	3.70	3.30	2.37	3.06	128.74
1893	2.46	1.96	4.28	43.53	*42.72*	9.84	6.64	3.62	2.55	2.73	2.30	3.06	125.69
1894	2.46	1.96	4.28	28.70	17.18	9.10	4.90	2.43	1.57	2.34	2.00	3.06	79.98
1895	2.46	1.96	4.28	4.80	2.99	4.55	4.63	2.45	1.67	1.73	2.00	3.06	36.58
1896	2.46	1.96	4.28	20.59	35.18	*32.48*	8.39	4.57	3.48	3.35	3.10	3.06	122.90
1897	2.46	1.96	4.28	*81.92*	24.75	9.82	26.13	*19.20*	7.77	5.85	3.68	3.06	*190.88*
1898	2.46	1.96	4.28	8.48	6.19	8.57	10.62	4.87	3.77	4.32	4.14	3.06	62.72
1899	2.46	1.96	4.28	14.07	11.06	14.19	11.88	6.49	4.67	4.41	3.93	3.06	82.46
1900	2.46	1.96	4.28	7.32	3.44	1.92	2.13	2.86	7.54	*16.58*	*13.64*	3.06	67.19
1901	2.92	2.41	5.12	28.76	17.99	12.44	10.67	6.37	4.70	5.02	4.49	3.65	104.54
1902	2.46	1.96	4.28	16.50	21.62	16.97	8.89	5.32	7.73	8.37	6.85	3.06	104.01
1903	4.28	3.43	5.64	27.58	14.49	8.66	3.86	2.82	4.91	7.99	5.71	5.26	94.63
1904	3.70	3.10	4.00	50.50	36.79	15.62	10.48	4.72	4.18	4.98	4.12	3.24	145.43
1905	2.70	2.30	4.60	7.50	21.80	12.51	11.29	17.59	*11.70*	8.96	6.61	5.30	112.86
1906	*4.70*	*3.84*	5.05	51.50	22.10	15.72	12.22	8.55	6.42	5.89	5.58	4.36	145.93
1907	3.76	2.64	8.24	38.39	12.20	15.58	8.80	5.36	5.06	5.27	3.74	3.22	112.26
1908	2.38	2.00	5.27	25.55	15.52	18.50	8.80	5.27	4.58	3.86	3.24	2.21	97.18
1909	1.87	1.36	2.48	11.25	8.28	8.06	10.12	15.00	8.32	5.97	4.93	*6.49*	84.13
1910	4.08	3.15	*22.60*	20.40	11.65	5.06	2.31	1.31	1.11	1.11	1.03	.83	74.64
1911	.56	.45	2.40	4.88	4.01	4.57	1.55	1.05	1.01	1.24	.96	.91	23.59
1912	.37	.28	.80	6.42	4.49	2.92	1.87	1.50	1.96	3.48	2.11	1.13	27.33
1913	.85	.56	.76	18.28	4.88	3.08	2.76	2.04	2.76	2.81	2.95	2.12	43.85
1914	1.36	1.04	2.44	7.75	6.86	12.48	7.61	2.92	3.06	3.39	3.50	3.12	55.53
1915	2.09	1.79	3.12	10.77	8.64	14.90	29.58	6.45	4.02	4.32	3.84	3.32	92.84
1916	2.26	1.68	2.86	57.60	29.46	17.58	*30.40*	13.20	10.28	8.20	7.20	4.75	185.47
1917	3.27	2.25	4.71	30.19	12.81	5.66	3.16	1.60	1.45	1.58	2.06	1.16	69.90
1918	.71	.48	4.00	4.69	4.96	5.08	2.26	1.94	1.47	1.09	1.69	1.80	30.17
1919	1.20	.60	2.99	14.36	8.98	4.79	18.55	8.98	3.59	3.14	3.69	4.10	74.97
Mean annual	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	90.87

NOTE.—Mean rate of flow 1882 to 1919=2,881 sec.-ft. Maximums shown in italics.

Run-off data for all of the watersheds listed in Table 3 were compiled in the same form as shown in Table 4 for Grand Forks, but the tables are not here given as all the records are now available, or soon will be, either in Water Supply Papers of the United States Geological Survey or in reports of the Dominion Water Power Branch, Department of the Interior, Canada.

The Grand Forks records cover the longest period of any in the Red River watershed and form, therefore, a basis for estimating probable future run-off quantities and rates of flow with a degree of

accuracy that may not be attained where the records cover short periods only.

When all available records had been compiled it was found that of the various watersheds listed in Table 5, run-off estimates for 16 (those listed in Table 3) may be based in part on measured run-off and in part on data resulting from a consideration of the various factors that affect run-off. That method must suffice also for eight other watersheds for which run-off has been measured on only parts of the areas. For the remaining 23 watersheds, estimates must be based entirely on a consideration of the various factors that affect run-off and comparisons with measured run-off from watersheds having somewhat similar characteristics.

TABLE 5.—*Recorded and estimated future maximum discharges from streams on Red River watershed.*

Stream.	Station.	Watershed area.	Period of measurements.	During summer floods.			During spring floods.		
				Maximum recorded discharge.	Estimated future maximum—		Maximum recorded discharge.	Estimated future maximum—	
					Discharge.	Run-off.		Discharge.	Run-off.
		Sq. mi.	*Years.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft. per sq. mi.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft. per sq. mi.*
Small streams	Browns Valley to Mustinka River.	291			1,455	5		1,455	5
Mustinka River	Wheaton	756	2		3,024	4	2,240	3,024	4
Do	Mouth	852			3,408	4		3,408	4
Small streams	Mustinka River to White Rock.	192			960	5		960	5
Lake Traverse outlet.	White Rock	1,335			2,670	2		2,670	2
Small streams	Fairmount	145			725	5		725	5
Bois de Sioux River.	do	1,480	1		2,960	2	255	2,960	2
Small streams	Fairmount to Breckenridge.	395			1,975	5		1,975	5
Bois de Sioux River.	Wahpeton	1,875			3,750	2		3,750	2
Otter Tail River	Fergus Falls	1,300	18	1,080	1,560	1.2	789	1,820	1.4
Otter Tail River tributaries.	Below Fergus Falls	540			2,160	4		2,160	4
Otter Tail River	Breckenridge	1,840			3,312	1.8		3,680	2
Small streams	Breckenridge to North Dakota Wild Rice River.	445			1,780	4		1,780	4
Red River	Above mouth of North Dakota Wild Rice River.	4,160			6,656	1.6		8,320	2
North Dakota Wild Rice River.	Lake Tewaukon	625			1,875	3		2,500	4
Do	Mouth, Wild Rice	2,210	1		3,315	1.5	1,779	4,420	2
Local drains	Fargo-Moorhead	65			520	8		455	7
Red River	do	6,435	18	7,720	9,652	1.5	7,440	11,580	1.8
Local drains	Moorhead to Sheyenne River.	95			665	7		570	6
Sheyenne River	Valley City	4,185	1		2,511	0.6	2,750	4,185	1
Do	Haggart	5,600	7	841	2,800	0.5	2,220	5,600	1
Do	Mouth	7,400			3,700	0.5		7,400	1
Red River	Below Sheyenne River mouth.	13,930			13,930	1		16,716	1.2
Buffalo River	Georgetown	1,175			5,875	5		5,875	5
Minnesota Wild Rice River.	Twin Valley	835	9	9,120	5,845	7	1,560	5,010	6
Do	Mouth	1,485			5,940	4		5,940	4

TABLE 5.—*Recorded and estimated future maximum discharges from streams on Red River watershed*—Continued.

Stream.	Station.	Watershed area.	Period of measurement.	During summer floods.			During spring floods.		
				Maximum recorded discharge.	Estimated future maximum—		Maximum recorded discharge.	Estimated future maximum—	
					Discharge.	Run-off.		Discharge.	Run-off.
		Sq. mi.	*Years.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft. per sq. mi.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft. per sq. mi.*
Goose River	Mouth	1,270			3,810	3		3,810	3
Sandhill River	do	425			1,700	4		2,550	6
Small streams	Sheyenne River to Grand Forks.	1,685			6,740	4		6,740	4
Red Lake	Outlet	1,950			1,950	1		2,925	1.5
Thief River	Thief River Falls	1,080	9	4,100	5,400	5	4,080	4,320	4
Red Lake River and Thief River.	do	3,600	10	7,600	10,800	3	7,040	9,000	2.5
Clearwater River	Red Lake Falls	1,330	9	6,700	6,650	5	3,990	6,650	5
Red Lake River	Crookston	5,320	19	14,400	15,960	3	14,400	15,960	3
Do	East Grand Forks	5,785			17,355	3		17,355	3
Red River	Grand Forks, N. Dak.	25,755	38	22,360	36,057	1.4	43,000	51,510	2
Turtle River	Mouth	705			2,115	3		2,115	3
Forest River	do	1,030			2,060	2		3,090	3
Snake River	do	760			2,280	3		2,660	3.5
Park River	do	885			2,212	2.5		2,655	3
Tamarac River	do	365			1,460	4		1,460	4
Small streams	Grand Forks to Drayton.	765			3,060	4		3,060	4
Two Rivers	Hallock	635	4	634	2,540	4	1,200	2,540	4
Do	Mouth	975			2,925	3		3,900	4
Small streams	Drayton to Emerson, Manitoba.	790			2,370	3		3,160	4
Pembina River	Neche	3,320	12	2,500	3,984	1.2	3,870	4,980	1.5
Do	Pembina	3,865			4,638	1.2		5,797	1.5
Red River	International boundary.	35,895	8	20,121	39,485	1.1	46,180	61,022	1.7

PRECIPITATION.

As it was found that precipitation records covered longer periods of time and were available for many more localities than were stream-flow records, a study of precipitation was undertaken for the purpose of supplementing the data on run-off.

The official records of the United States Weather Bureau were used as the basis for the precipitation studies. The investigation developed that total annual, total and maximum monthly, and maximum and excessive daily and storm precipitation, are of much greater significance in the project than are mean or average quantities and rates. It developed also that accumulations of precipitation in the forms of snow and ice are important factors in estimating stream discharge for March and April.

Records of monthly and annual precipitation at Breckenridge, Minn., and Pembina, N. Dak., are available for 48 years (1872 to 1919) and at Moorhead, Minn., for 39 years (1881 to 1919). Other weather-observation stations have been established from time to time

until in 1921 about 50 were maintained within the Red River watershed (see fig. 1). Daily precipitation records are available for twenty or more stations for the period 1892 to 1919.

DISTRIBUTION OF PRECIPITATION.

In making the study of precipitation data the contributing area south of the international boundary was divided into seven areas as indicated in figure 5. This facilitated the determination of the precipitation on watersheds of various tributary streams and on areas above certain stream-gaging stations; it also made evident the relations between size of watershed and intensity of precipitation.

FIG. 5.—Outline watershed map of Red River of the North, showing subdivisions for precipitation studies.

The precipitation records were considered in four classes—annual, monthly, and storm periods, and the period during which snow is stored. The annual, monthly, and storm precipitations were computed from the records for each area and weighted averages were computed for certain larger areas which comprise two or more of the subareas. The records prior to 1892 are too meager to afford satisfactory basis for estimating the distribution of precipitation over these areas.

MONTHLY AND ANNUAL PRECIPITATION.

In Table 6 the averages of the records for the watershed above Grand Forks are shown. The "weighted averages" for 1892 to 1919 were computed by calculating separately the volume of monthly precipitation in each of the five subdivisions of that watershed to find the total volume for the area, and then reducing that quantity to an equivalent depth in inches over the watershed for each month and year.

TABLE 6.—*Average precipitation on Red River watershed above Grand Forks, N. Dak. (compiled from record of U. S. Weather Bureau).*

Year.	No. of stations.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
		In.	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*
1882	3	0.81	0.65	1.84	1.68	3.49	5.40	4.92	1.31	1.03	4.05	1.42	0.76	27.36
1883	3	.55	.40	.18	1.17	2.74	1.48	2.98	3.41	1.91	3.06	.17	.69	18.74
1884	3	.35	.79	.74	1.10	3.05	1.93	4.75	5.87	2.45	2.83	.43	.97	25.26
1885	7	.35	.15	.37	2.79	1.49	4.45	4.01	1.49	1.71	.56	93	.43	18.73
1886	7	.68	.58	.41	3.21	1.85	3.00	2.91	1.47	1.67	1.40	1.17	.45	18.80
1887	8	.64	.53	.46	1.70	2.18	4.42	4.48	2.58	1.34	1.45	.42	1.57	21.77
1888	8	.72	.29	.91	1.21	1.69	3.92	4.21	1.42	.97	1.26	.28	.21	17.09
1889	8	.81	.78	.37	1.12	1.82	1.76	2.61	2.14	2.53	.07	.43	.89	15.33
1890	8	.61	1.07	.65	.77	1.43	5.46	2.54	2.38	2.36	2.46	.28	.25	20.26
1891	7	.43	1.21	1.21	2.99	2.00	4.61	3.99	2.64	3.01	1.59	.85	1.09	25.62
1892	14	.35	.71	1.17	3.15	4.07	3.19	3.20	2.84	.70	.28	1.06	.25	20.97
1893	18	1.06	.82	1.36	2.77	1.82	3.00	3.08	2.77	1.03	1.19	.50	1.05	20.45
1894	19	.46	.34	1.77	3.62	2.62	3.64	.75	1.49	1.31	2.44	.37	.51	19.32
1895	17	.49	.38	.10	1.44	2.16	6.34	3.32	2.14	1.32	.24	1.41	.21	19.55
1896	20	.86	.67	1.35	*4.94*	*5.17*	3.35	1.69	2.13	2.58	1.73	*2.33*	.40	27.20
1897	20	1.22	1.46	1.23	.94	.89	5.99	*6.93*	1.23	.68	1.19	.28	.30	22.34
1898	21	.09	.55	.84	1.37	2.60	3.63	3.86	2.27	1.66	2.18	.46	.29	19.80
1899	22	.51	.21	.76	1.52	4.55	3.41	2.45	3.80	1.03	1.61	.42	.36	20.63
1900	22	.28	.42	1.06	1.24	.83	1.47	2.90	*7.40*	*4.52*	2.78	.55	.33	23.78
1901	22	.32	.51	1.25	1.85	.96	6.75	5.58	2.17	2.39	*3.20*	.27	.77	26.02
1902	22	.20	.62	*1.91*	1.56	3.97	3.60	2.72	3.38	.79	2.65	.44	.62	22.46
1903	23	.71	.45	.73	1.60	3.12	1.31	3.24	4.35	3.36	1.81	.30	.79	21.77
1904	23	.38	.91	1.66	2.31	2.15	4.60	2.64	1.53	3.06	2.00	.11	.75	22.10
1905	24	.38	.25	.89	1.41	5.04	4.96	5.08	3.86	1.97	1.09	1.82	.17	26.92
1906	23	.99	.17	.57	2.03	4.77	4.27	3.10	2.91	1.91	1.08	1.93	1.23	24.96
1907	23	1.26	.27	.64	.97	1.56	3.96	3.09	2.62	2.41	1.07	.18	.45	18.48
1908	23	.19	*1.48*	1.27	1.26	3.86	3.55	2.56	3.05	1.39	1.31	1.34	.58	21.84
1909	22	.60	.32	.33	1.09	4.18	3.37	4.01	3.71	1.20	1.20	.72	*1.52*	22.25
1910	21	.29	.55	.79	1.61	.79	1.53	1.65	1.32	2.14	.61	.50	.43	12.21
1911	24	1.25	.75	.41	1.80	3.56	3.30	2.51	3.19	2.51	1.34	1.01	.54	22.17
1912	29	.32	.20	.34	2.49	3.81	2.13	4.39	3.57	3.98	.56	.14	.70	22.63
1913	29	.45	.14	1.05	1.06	1.96	2.91	3.56	2.58	2.81	2.71	.22	.04	19.49
1914	33	.53	.37	1.17	2.09	2.79	7.11	3.21	2.93	1.59	1.62	.43	.38	24.22
1915	35	.63	1.05	.31	1.32	3.61	*7.56*	2.54	1.19	2.45	1.10	.72	.58	23.06
1916	36	*1.57*	.43	1.64	2.06	3.35	4.80	4.20	4.06	3.74	.53	.09	1.29	*27.76*
1917	34	.70	.86	.42	1.85	.27	1.97	2.02	1.21	2.27	1.02	.19	.63	13.41
1918	33	.54	.19	.34	2.35	3.26	2.00	2.89	4.22	.41	1.22	1.18	1.04	19.64
1919	33	.29	.66	.74	1.65	3.77	3.26	4.53	3.39	1.22	1.12	1.82	.57	23.02

NOTE.—Figures show "weighted averages" for 1892 to 1919. Maximums shown in italics.

The maximum annual precipitation over the whole watershed since 1885 occurred in 1896. While slightly greater average annual precipitation was recorded at two observation stations for 1880 and 1882, and a much greater amount for 1878, than is shown for 1896, it is believed the earlier records should not be taken to represent the aver-

ages for the whole watershed area, because observations were recorded at but two or three stations. In 1885 the number of stations was increased to seven and these were distributed quite widely over the watershed; so the averages shown in Table 6 for the period subsequent to 1885 are considered more reliable than those for the earlier years.

TABLE 7.—*Maximum, mean, and minimum annual precipitation for subdivisions of the watershed (see fig. 5) for period 1892 to 1919.*

Watershed.		Maximum.			Mean.		Minimum.		
Subdivision.	Area (square miles).	Year.	Depth (inches).	Volume (billions of cubic feet).	Depth (inches).	Volume (billions of cubic feet).	Year.	Depth (inches).	Volume (billions of cubic feet).
1	4,225	1916	35.2	345.3	24.2	238.3	1910	13.6	133.3
2	2,210	1906	32.5	166.6	21.8	111.5	1910	13.1	67.2
3	9,815	1905	27.7	632.3	21.3	485.5	1910	11.4	260.2
4	4,185	1896	22.2	215.8	17.3	168.4	1917	11.8	114.6
5	5,320	1896	31.6	391.1	24.0	296.9	1917	12.2	151.1
6	6,275	1896	24.5	356.6	19.0	276.1	1917	12.1	176.1
7	3,865	1904	25.1	225.6	17.7	158.9	1897	10.3	92.6
1 and 2 above Fargo and Moorhead	6,435	1916	34.2	511.9	23.4	349.8	1910	13.4	200.5
1 to 5 above Grand Forks.	25,755	1916 1896	27.8 27.2	1,661.2 1,628.3	21.7	1,300.6	1910	12.2	730.9
1 to 7 above international boundary.	35,895	1896 1916	26.5 25.72	2,209.8 2,144.8	20.8	1,735.6	1910	12.3	1,029.5

Figure 6 shows the amount and distribution of the annual precipitation for 1896, which is the year of greatest precipitation from 1885 to 1919, inclusive. Table 7 shows the maximum, mean, and minimum annual precipitation for the seven subdivisions of the watershed shown in figure 5, also like quantities for the watersheds above Fargo, above Grand Forks, and for the entire area south of the international boundary.

The maximum precipitation over sub-areas 4, 5, and 6 occurred in 1896, the year in which the precipitation was maximum over the whole watershed. In 1916 occurred the maximum on sub-area 1, on subareas 1 and 2 combined (south of Fargo and Moorhead), and on the watershed above Grand Forks which comprises sub-areas 1 to 5, On subarea 2 maximum precipitation occurred in 1906; on No. 3, in 1905; and on No. 7, in 1904. The precipitation on large portions of the watershed during the first six months of 1916, and during the last six months of 1909, was considerably above normal and caused excessive run-off. Figure 7 indicates the total precipitation for these half-year periods. This combination year was used later in computing run-off. The total, however, does not exceed the 1896 precipitation (fig. 6) except on the small area south of Red Lake which was covered by the storm of July 20–22, 1909.

The distribution of the mean annual precipitation for the entire watershed is indicated on figure 8. This map was prepared by

plotting the average precipitation at stations having records covering 10 or more years. The maximum and the mean annual precipitation as indicated on figures 6 and 8, respectively, have been greatest in the southeastern portion of the watershed and have diminished in intensity to the west and north.

Average depths of monthly and annual precipitation in the seven subdivisions (see fig. 5) of the watershed for the period 1892 to 1919 were computed. The depths averaged were measured at from 2 to

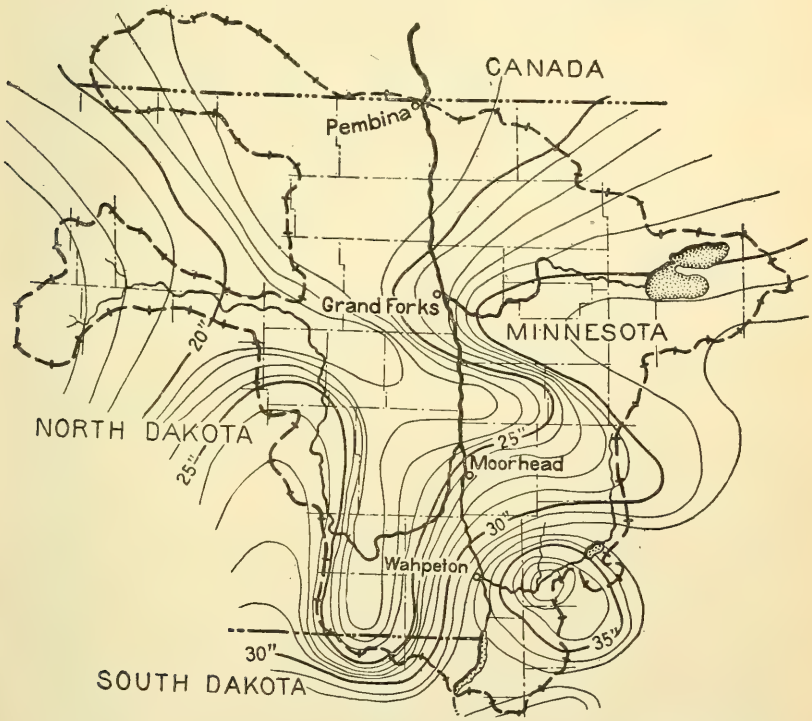

FIG. 6.—Total precipitation during 1896 on watershed of Red River of the North.

12 weather observation stations in each sub-area. The total volume of precipitation for maximum months and for months immediately preceding months when run-off above Grand Forks has been maximum are shown in figure 9.

As is indicated in the various figures and tables, maximum precipitation for April, May, and November occurred in 1896 when the annual precipitation was maximum. In 1900 occurred the maximums for August and September but the total precipitation for that year was considerably below the maximum. In no case has the maximum for more than one of the remaining seven months occurred in a single year; each has occurred during a year for which the annual precipitation was above the mean for the watershed.

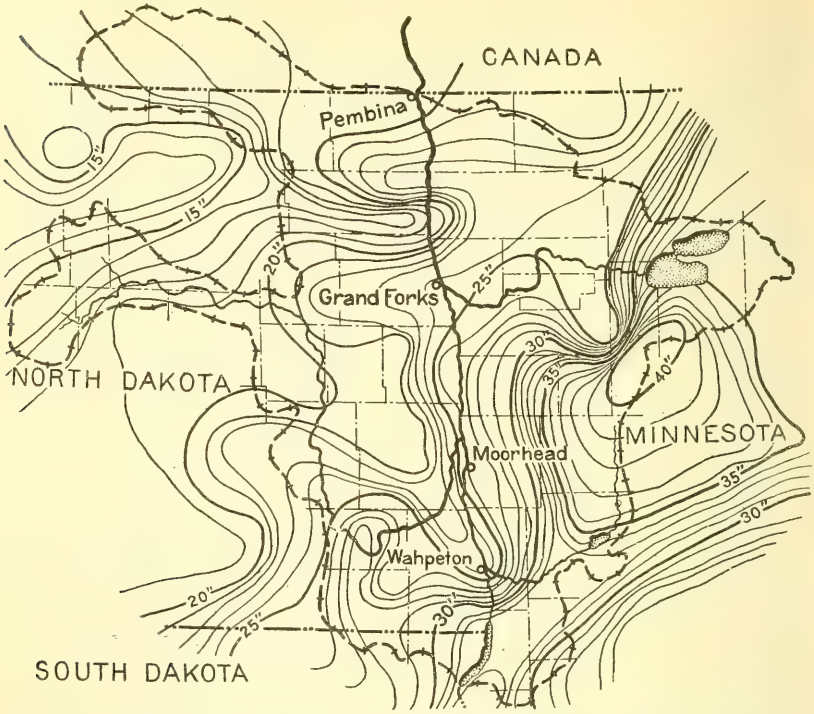

FIG. 7.—Precipitation on watershed of Red River of the North during 12 months comprising January to June, 1916, and July to December, 1909.

FIG. 8.—Mean annual precipitation on watershed of Red River of the North.

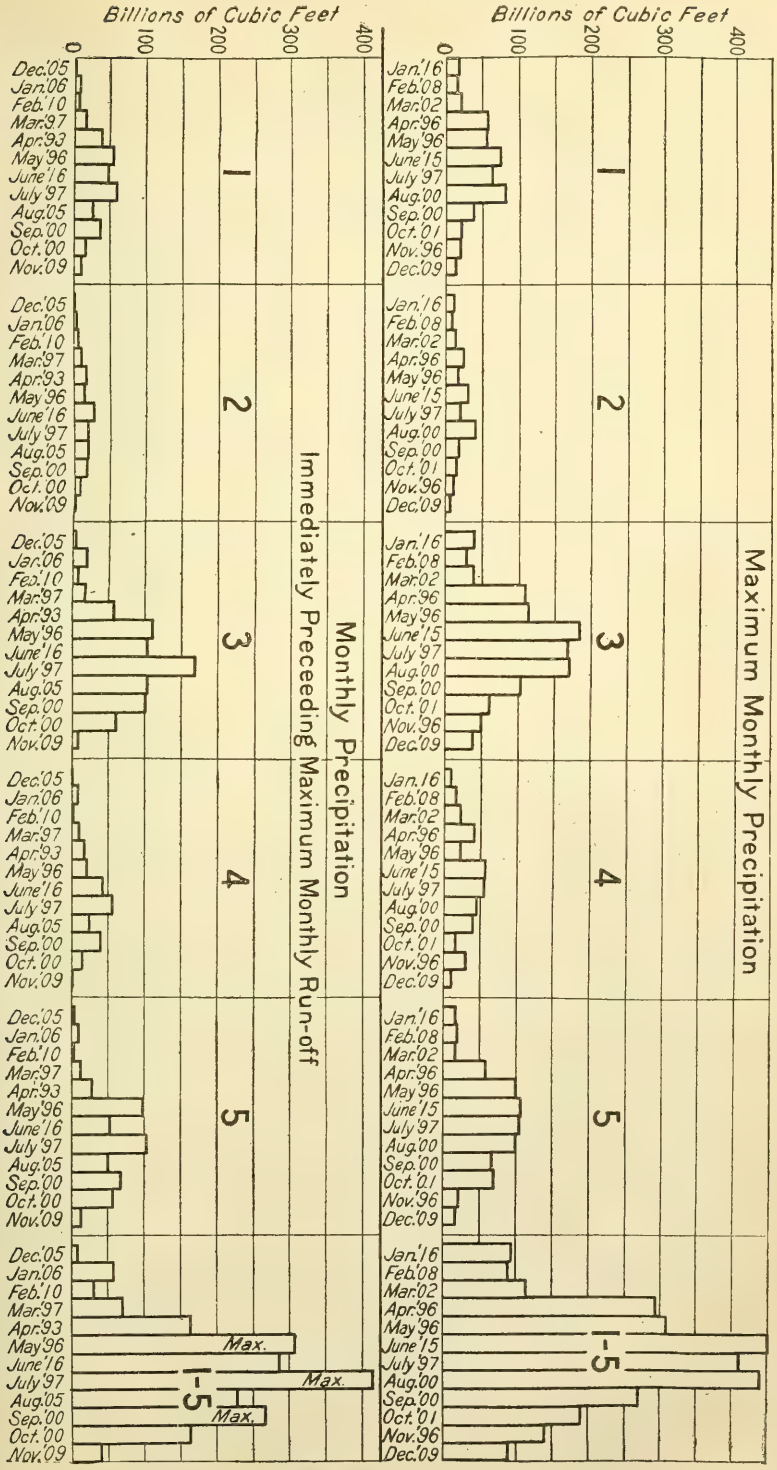

FIG. 9.—Precipitation on five subdivisions of Red River watershed. (See fig. 5.)

A study of the annual and monthly records indicates that no combination of excessive monthly precipitation is likely to occur which will produce a maximum annual precipitation of more than 30 inches over that part of the Red River watershed south of the international boundary. It appears also that the maximum annual precipitation for the extreme western portions of the watershed will probably not exceed 25 inches, and that the maximum for areas of 2,000 square miles or greater in the eastern sections of the watershed will probably not exceed 37 inches. The maximum annual precipitation on the watershed above Fargo and on the Red Lake River watershed above Crookston will probably not exceed 36 inches. From the maximum of 37 inches south of Lake Traverse and 36 inches south of Red Lake intensities diminish toward the north by about 2 inches per degree of latitude, and toward the west by about 3 inches per degree of longitude. These maximum conditions are likely to occur but once in a long period, perhaps 50 to 75 years.

The records further show that maximum annual and monthly precipitation on the smaller watersheds have not occurred simultaneously on the different sub-areas. It is improbable, therefore, that the estimated maximum precipitation will occur on all the sub-areas in any one year.

STORM PRECIPITATION.

Records were compiled of all storms within the Red River watershed with precipitation of 2 inches or more in 24 hours. For each storm the depths of precipitation for one day, two days, three days, and for the duration of the storm were determined for all observation stations within or near the watershed. The records cover the 26-year period 1894 to 1919, and include 130 storms of from two to eight days' duration (see Table 8). By plotting isohyetals on a map of the Red River watershed the intensity and extent of the storms were made evident. The areas covered by storms during the years 1894 to 1904 are somewhat indefinite, as the number of records is small. For the period 1905 to 1919 many more records are available and the areas covered can be more accurately determined. During many of the storms excessive precipitation occurred in but few localities and covered but small areas. The relative importance of the storms was determined from the isohyetal maps.

TABLE 8.—*Storm periods during which precipitation of 2 inches or more occurred on Red River watershed in the United States.*

Year.	Date.	Length of storm period.	Year.	Date.	Length of storm period.
		Days.			*Days.*
1894	Apr. 15–20	6	1896	Mar. 4–7	4
	June 26–28	3		Apr. 8–13	6
1895	June 2–5	4		Apr. 25–30	6
	June 6–10	5		May 11–17	7
	July 4–8	5		June 4–8	5

TABLE 8.—*Storm periods during which precipitation of 2 inches or more occurred on Red River watershed in the United States*—Continued.

Year.	Date.	Length of storm period.	Year.	Date.	Length of storm perion.
		Days.			*Days.*
1897	June 1–3	3	1905	July 3–5	3
	June 14–19	6		Aug. 13–17	5
	June 27–29	3	1906	May 23–26	4
	July 1–4	4		June 6–9	4
	July 6–9	4		June 17–21	5
	July 17–22	6		July 31–Aug. 2	3
1898	Apr. 29–May 1	3		Aug. 20–25	6
	May 17–22	6		Sept. 11–16	6
	June 21–27	7	1907	June 9–11	3
	June 30–July 2	3		Aug. 4–5	3
	Aug. 21–23	3		Aug. 26–28	3
1899	May 26–31	6	1908	June 5–8	4
	June 1–6	6		June 17–19	3
	June 10–14	5		June 21–24	4
	July 2–6	5		Aug. 26–31	6
	Aug. 6–11	6	1909	May 29–June 1	4
	Aug. 15–20	6		July 11–14	4
1900	Apr. 23–29	7		July 19–21	3
	July 1–7	7		Aug. 6–8	3
	Aug. 4–11	8		Aug. 10–13	4
	Aug. 19–25	7	1910	Apr. 14–18	5
	Sept. 4–5	2		July 22–24	3
	Sept. 8–11	4		Sept. 4–6	3
	Sept. 14–15	2	1911	May 9–12	4
	Sept. 23–25	3		May 14–16	3
1901	June 9–12	4		June 1–4	4
	June 14–16	3		July 22–24	3
	June 20–25	6		Sept. 4–7	4
	July 2–5	4	1912	Apr. 12–15	4
	July 23–28	6		May 2–5	4
	Sept. 10–14	5		June 13–16	4
	Oct. 5–9	4		July 26–28	3
1902	Mar. 23–27	5	1913	July 2–5	4
	Apr. 21–22	2		Aug. 17–21	5
	May 1–3	3		Sept. 9–11	3
	May 15–21	7		Oct. 4–6	3
	June 5–7	3	1914	Apr. 26–28	3
	July 4–6	3		June 4–9	6
	July 28–30	3		June 26–27	2
	Aug. 27–31	5		July 21–22	2
	Oct. 23–26	4		Sept. 12–14	3
1903	May 19–23	5		Oct. 8–12	5
	June 29–July 4	6	1915	June 10–13	4
	July 26–28	3		June 26–28	3
	Aug. 26–28	3	1916	Apr. 18–21	4
	Sept. 11–13	3		May 13–16	4
	Oct. 2–4	3		June 28–30	3
1904	Apr. 7–10	4		Sept. 9–10	2
	May 11–13	3	1917	June 4–8	5
	June 2–5	4		June 10–13	4
	June 8–10	3		July 4–6	3
	June 22–25	4		Sept. 18–20	3
	July 2–4	3	1918	Apr. 16–22	7
	July 13–14	2		Apr. 26–29	4
	Aug. 17–22	5		May 18–21	4
	Aug. 30–Sept. 3	5		May 29–June 1	4
1905	May 2–5	4		July 24–28	5
	May 9–12	4		Aug. 16–22	7
	June 3–6	4	1919	June 20–23	4
	June 23–25	3		July 1–4	4

Summary.

Length of storm period (days).	Number of storms, 1894 to 1919.								Total.
	March.	April.	May.	June.	July.	August.	September.	October.	
2		1		1	2		3		7
3		2	3	12	11	5	6	2	41
4	1	4	9	13	6	1	2	2	38
5	1	1	1	5	3	4	2	1	18
6		3	2	5	2	4	1		17
7		2	2	1	1	2			8
8						1			1
Total	2	13	17	37	25	17	14	5	130

From the 130 storms 13 were selected for which the precipitation was exceptionally heavy over considerable area. The date, duration, and location of each storm and amount of precipitation at one station are shown in chronological order in Table 9. Three storms of maximum intensity for areas which vary in size from 300 to 35,000 square miles were selected for more detailed study. Depth-area curves for these three storms are shown in figure 10. The run-off resulting from each of these three storms was measured at stream gaging stations at one or more points in the watershed.

TABLE 9.—*Storm precipitation on Red River watershed in the United States.*

Year.	Date.	Length of storm period.	Total precipitation at center of storm.	Location of storm center.	Maximum 24-hour precipitation at one observing station.
		Days.	*Inches.*		*Inches.*
1897	June 27–29	3	4.66	Amenia, N. Dak.	2.35
1897	July 17–22	6	7.42	Wild Rice, N. Dak.	5.86
1899	Aug. 17–20	4	8.18	Leech Lake, Minn.	4.31
1900	Aug. 4–11	8	10.50	Alexandria, Minn.	3.15
1908	Aug. 26–31	6	6.93	Crookston, Minn.	5.85
1909	July 20–22	3	11.10	Beaulieu, Minn.	10.75
1915	June 10–13	4	3.91	Detroit, Minn.	2.75
1915	June 26–28	3	5.04	Mayville, N. Dak.	3.98
1916	Apr. 18–21	4	2.58	Campbell, Minn.	2.26
1916	May 13–16	4	3.34	Fullerton, N. Dak.	2.94
1916	June 28–30	3	3.84	Beardsley, Minn.	3.67
1919	June 20–23	4	6.13	Cando, N. Dak.	5.30
1919	July 1–4	4	9.02	Warroad, Minn.	4.92

The storm of July 17–22, 1897, covered the entire Red River watershed. The precipitation was the maximum of record during any storm covering the entire watershed and was maximum for any portion of the watershed 8,000 to 35,000 square miles in area. Isohyetals for the storm are shown in figure 11. Following this storm there occurred the highest stage of record at Grand Forks for July and August, and the total discharge of the river for August, 1897, was the recorded maximum for August. Less than a month earlier than the July storm (June 27–29) another storm had occurred which may have increased the run-off after July 17 in certain localities.

During the storm of July 1 to 4, 1919, precipitation was the maximum that has been recorded on areas of 2,000 to 8,000 square miles within the Red River basin. Isohyetals for this storm are shown in figure 12. This storm produced very high stages on Red Lake River, Thief River, Clearwater River, Roseau River, and Two Rivers, and caused heavy losses from drowned crops in eastern Marshall County and in Roseau County, Minn. Nine inches of rain fell in four days over an area of approximately 390 square miles.

The maximum storm precipitation that has been recorded for areas of 300 to 2,000 square miles occurred on July 20–22, 1909 (see fig. 13). The maximum 24-hour precipitation recorded for one station was 10.75 inches. Besides being maximum for the Red River Valley this storm, according to investigations made by the Miami (Ohio) Conservancy District, was one of the greatest that occurred in the upper Mississippi Valley during the period 1892–1916 and was the only one of 49 great storms in the northern portion of central and eastern United States that shows a precipitation in excess of 6 inches in 3 days over a considerable area in the Red River watershed. This storm was central over the watershed of the Wild Rice River in Minnesota and caused a more intense run-off to reach Twin Valley, Minn., than has been recorded on any other watershed of

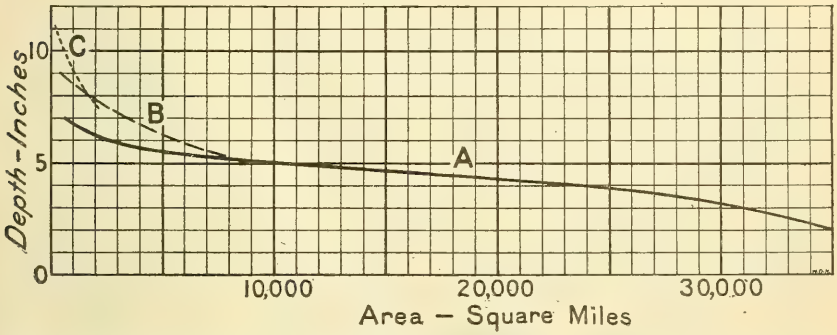

FIG. 10.—Depth-area curves for maximum storm precipitation on watershed of Red River of the North. A, Storm of July 17–22, 1897; B, storm of July 1–4, 1919; C, storm of July 20–22, 1909.

similar size (835 square miles) in the Red River basin. This storm precipitation so far exceeded any other that has been recorded in the Red River Valley that it is doubtful whether any as intense as that will occur again within 75 or 100 years on an area of 800 square miles anywhere in the valley.

Relative to the other 10 storms listed in Table 9, the records for several are of special importance. In some cases the heavy precipitation covered areas from which the run-off was measured, while areas covered by some were outside the watershed to the east and southeast and no measurements were made. The storm of June 20–23, 1919, was central over Towner County, N. Dak. It was unusual in that the heaviest precipitation occurred in the northwestern section of the Red River watershed. The maximum 4-day precipitation was slightly more than 6 inches but that intensity occurred over a comparatively small area. This storm, however, caused heavy precipitation over the Lake Traverse watershed. The records are meager but apparently on that area the rainfall was from 2½ to 4 inches in

48 hours. The run-off from this storm raised the water in Lake Traverse approximately 2 feet but did not materially increase the discharge from the lake.

The effect of the two storms of June 10–13 and June 26–28, 1915 (fig. 14), is quite marked in the run-off records of Red River at Fargo, Grand Forks, and Emerson. The monthly precipitation for June of that year was maximum. Apparently this was largely due to these two storms which covered large areas in the central portion

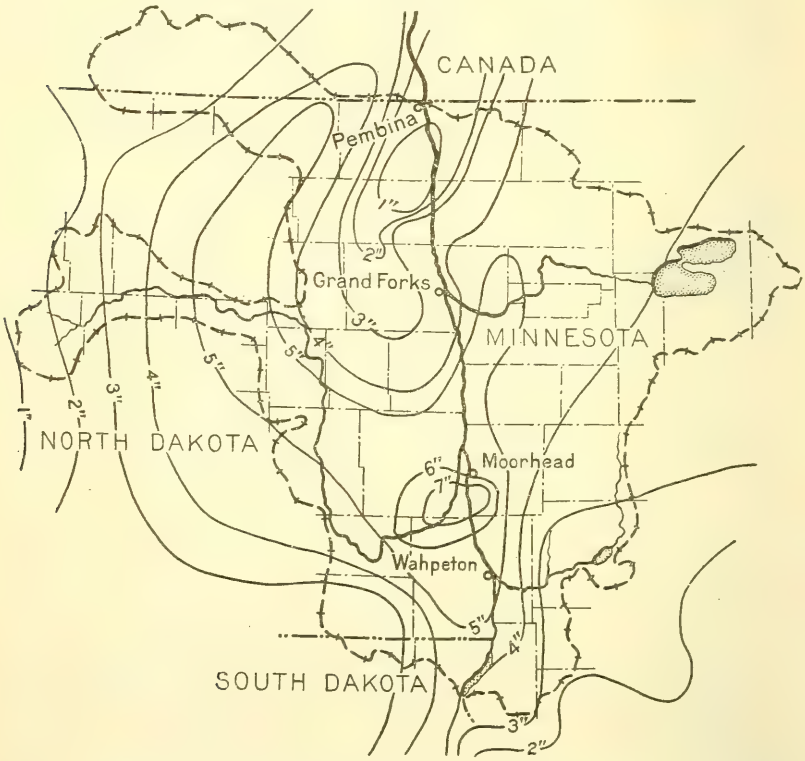

FIG. 11.—Maximum 6-day storm rainfall on watershed of Red River of the North, July 17–22, 1897.

of the watershed above Grand Forks. The run-off for the following month was very close to maximum at that station. Investigation of the monthly and storm precipitation data (see Table 8, Summary) showed that one or more storms occurred during each month March to September, inclusive, and that the excessive monthly precipitation of this period was due largely to excessive storms.

In the period 1894–1919 excessive storm precipitation, causing maximum or nearly maximum monthly precipitation, occurred during each month just prior to the months from May to October for which the run-off was maximum above Grand Forks. Thus May,

1896, July, 1897, and September, 1900, months of maximum precipitation, were followed by months of maximum run-off, June, August, and October, respectively. Again during May, 1896, and May, 1904, the run-off was near the May maximum for the period 1894 to 1919, because of storms in April and the first half of May in each of those years.

Maximum run-off during July, 1916, at Grand Forks was due to excessive storm precipitation in June and to heavy monthly precipi-

FIG. 12.—Maximum 4-day storm rainfall on watershed of Red River of the North, July 1–4, 1919.

tation (approaching maximum) for June and July. Maximum run-off during September, 1905, was due largely to heavy storm precipitation during the last half of August over the central portion of the watershed.

Thus it appears that maximum monthly precipitation due largely to excessive storm precipitation over a considerable portion of the Red River watershed, during the months April to October, has materially increased the run-off from the watershed; however, maximum monthly precipitation may produce in the following month run-off approaching maximum even though no maximum storm precipitation occurs.

SNOW.

In the Red River Valley snow has an important effect on run-off during March and April. Snow accumulates in varying quantities during parts or all of the months of November to March, inclusive. The run-off resulting from this stored precipitation was studied for the period for which data were available, 1893 to 1920, inclusive. Weather Bureau records of snow and ice conditions, showing the amount of stored snow remaining on the ground each week from

FIG. 13.—Maximnm 3-day storm rainfall on watershed of Red River of the North, July 20–22, 1909.

December to March, inclusive, were summarized and are shown in figure 15. It was found that when a considerable portion of the watershed was covered with snow to a depth exceeding 15 inches during the winter, and when near March 1, 12 inches or more of snow remained on the watershed, high stages would occur in the principal streams. In 1893, 1897, 1904, 1907, 1916, and 1920, when flood stages occurred, this relation was found to be true. The only exception was 1917, when the Red River did not quite reach flood stage, although there was quite a heavy snow covering on the watershed (see fig. 15). On March 1, 1920, the snow was from 6 inches to 15 inches in depth (average about 10 inches): this snow melted rapidly during the first half of March and the run-off therefrom

caused comparatively high stages of the Red River during the last week in March and the first week in April. This investigation showed for the highest flood of which we have record (that of April, 1897) that just prior to the spring break-up the average depth of snow over the watershed was 26 inches, and that all of this snow melted in approximately 20 days. The data also showed that all of the larger floods that have occurred on the Red River have been due mainly to the melting of snow over the watershed, rather than to precipitation

FIG. 14.—Storm rainfall on watershed of Red River of the North, June 26–28, 1915.

at the time the flood occurred, though in some cases precipitation at the time the snow was melting has undoubtedly caused stages somewhat higher than otherwise would have occurred. That rains in April prolong the flood period is indicated by the diagrams for 1904 and 1916, figure 15.

Records show that nearly every year more than 25 per cent of the annual run-off occurs in April, although the precipitation for April is seldom excessive and usually is less than 10 per cent of the annual precipitation. This high percentage of run-off during April is due to the melting of the snow stored throughout the winter months and to the more or less impervious condition of the ground at the time of the spring thaw.

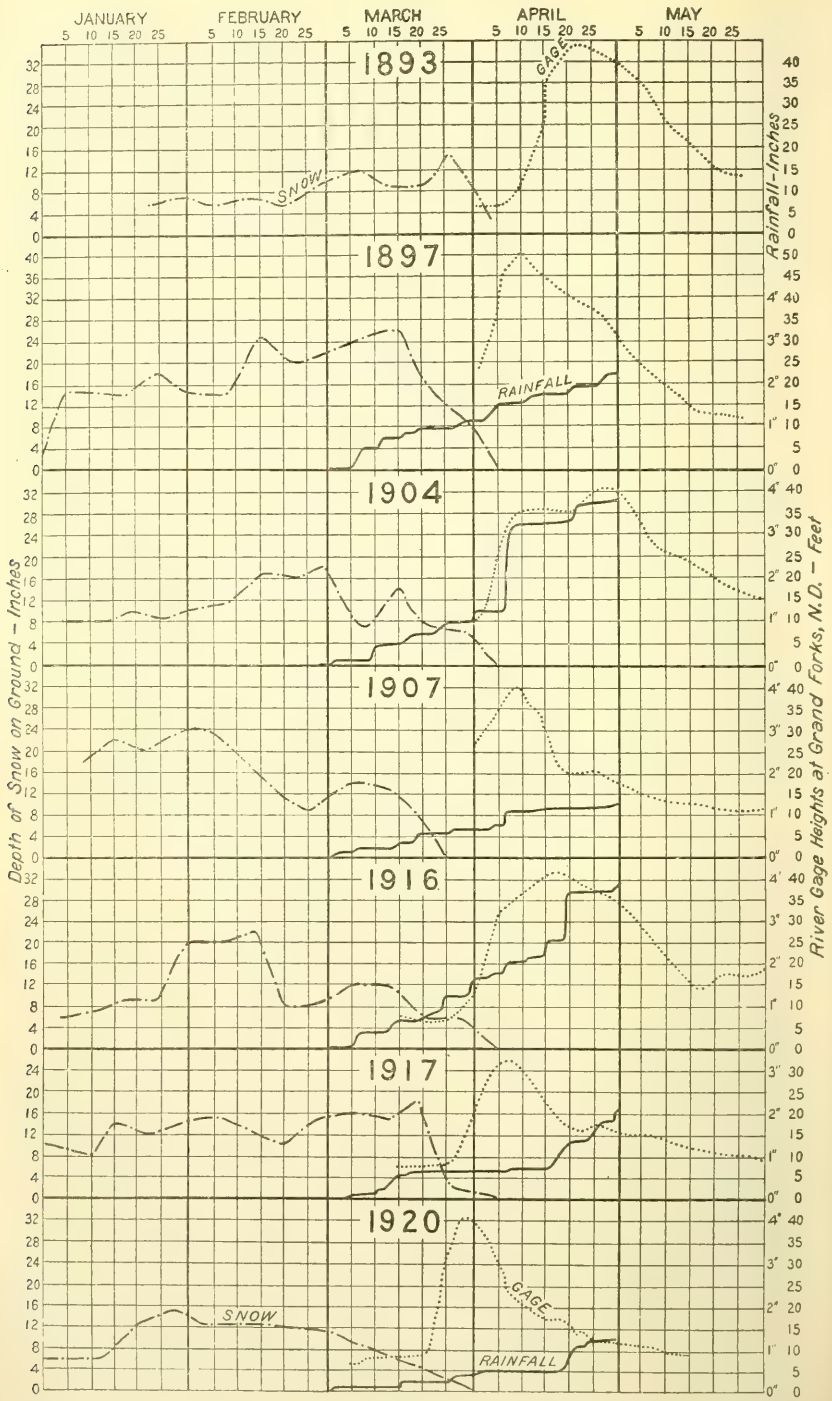

FIG. 15.—Average depth of snow and rainfall over watershed, and stages of Red River of the North at Grand Rapids, N. Dak., for years when floods occurred.

OTHER FACTORS AFFECTING RUN-OFF.

TOPOGRAPHY.

Some of the main topographic features have been described. The general topography of the various watersheds is indicated in figure 1; areas are given in Table 1.

In the great central portion of the watershed comprising the area termed "the valley," the surface is nearly level. The run-off there never is rapid. In the highest portions, comprising the areas draining to the upper parts of the tributary streams, large areas are flat and nearly level while others are somewhat rough. Depressions of every size are numerous; some are lakes while others are merely marshy spots and "pot holes." The run-off there is even more slow than in the valley unless it is modified by artificial drainage to carry water from the flat areas and depressions. Between the two portions of the watershed just described is located the area just outside the most recent shore lines of the ancient glacial lake, Agassiz. Here the surface slopes are steeper and comparatively regular and vary from a few feet to 25 or even 50 feet per mile. Much of this area is well drained naturally. The run-off from it is more rapid than from other parts of the watershed, but even here it could hardly be termed "quick." Considering the area as a unit, probably on no other watershed of equal size within the United States is the effect of the topography on run-off more nearly uniform over the whole area.

SIZE AND SHAPE OF THE WATERSHED AREAS.

The size of a watershed area is the principal factor to be considered in determining the volume of run-off originating on the area, for, approximately speaking, volume of run-off varies directly with the size of watershed. This relation, however, does not hold as between size of watershed and rate of run-off, as the rate of run-off per unit of area decreases as the size of watershed increases. This is true because the most intense storm precipitation and the most rapid melting of snow occur on relatively small areas, and the time of occurrence of the maximum rates of run-off from these separate small drainage areas is seldom, if ever, such as to concentrate these maximum discharges in the main outlet. The relation of size of drainage area to rate of run-off per square mile for various areas in the Red River watershed is indicated in Table 5.

The shape of the watershed of the Red River tends to produce quick run-off. As the width of the area nearly equals its length, the run-off from large portions of the watershed tends to concentrate at certain points. The same conditions are found in many subdivisions of the watershed, as for example the area above Grand Forks, that above Fargo, and watersheds of tributaries as follows: The

Bois de Sioux above Wahpeton, the Buffalo River, the Goose River, the Red Lake River above Crookston, Two Rivers, and the Minnesota Wild Rice River above Twin Valley. On certain other tributary streams where the ratio of width to length is small, the shape tends to prevent a concentration of water in the lower reaches since the water from lower part runs off before that from the upper portion reaches the main stream. On such streams the period of storm run-off is prolonged, but the rate of discharge is not so high as from equal areas where breadth and length are approximately the same. The Sheyenne River is the largest tributary having a long, narrow watershed. The Otter Tail, Sand Hill, and Pembina watersheds are also of this type.

TEMPERATURE.

The relation between prevailing temperature and precipitation and run-off was studied in some detail. As has been noted previously a large amount of precipitation accumulates on the ground in the form of snow. In the spring, owing to the rise in temperature which may sometimes be accompanied by rain, this accumulation is suddenly carried into the tributaries thus causing maximum floods. The relation which temperature bears to the magnitude of the spring flood depends on, (1) the rate and the amount of the temperature changes; (2) whether the temperature rise occurs simultaneously over the whole or large portions of the valley, or progresses from the upper to the lower portion of the watershed. Since the Red River flows north, if snow covers large portions of the watershed a rise in temperature that moves gradually northward will tend to cause a greater flood than will a simultaneous temperature rise in all parts of the area. Temperature is an important factor as affecting evaporation, and evaporation limits run-off quantities very materially.

In the spring of 1897 when occurred the greatest flood for which reliable records are available, there was a snow covering on March 15 of approximately 26 inches. The temperature rose slowly between March 14 and March 25; after March 25 the temperature rose rapidly and by April 5 the snow had disappeared. On April 10 the maximum flood stage occurred at Grand Forks. There was very little rainfall in the last 10 days in March, approximately one-half inch in the first five days in April, and the precipitation for April was only one-half the normal. High temperature and the warm rains melted the deep snow covering and caused the surface water to move so quickly into the streams that the amount which percolated into the soil probably was comparatively small and opportunity for loss by evaporation was limited. In a similar manner rapid rise in temperature occurring simultaneously over central and northern por-

tions of the valley in 1904 and 1916 produced higher stages than otherwise would have prevailed in the streams.

VEGETAL COVER.

On areas having moderate slopes such as are found in practically all parts of the Red River watershed, vegetation such as small grains, grasses, potatoes, or other plants whose stalks or leaves form a more-or-less intricate mass through which run-off must pass, tends to decrease run-off. The velocity of flow is retarded by the obstructions thus offered and the time during which evaporation, absorption by the soil, and transpiration of plants may occur is increased. This retarding effect would be greatest from June to September when plant growth is most luxuriant, and would be relatively small during March, April, and part of May, before plants are high enough to obstruct surface flow.

ARTIFICIAL DRAINAGE.

The function of artificial drainage is the disposal of excess water. Usually it is essential that such water be removed more quickly than it flows off through natural channels. This fact in itself would seem to imply an increased run-off rate as a result of artificial drainage. The drainage, by means of open ditches, of areas which have served as natural reservoirs—such as permanent swamps, marshes, ponds, and lakes—removes large quantities of excess water during the initial period of the operation of the drains. After drains have been in operation for a time the amount of discharge is diminished by whatever water is absorbed by the drained soil and by whatever amount evaporation and transpiration are increased. One effect of tile drainage is similar to that just stated, the run-off being decreased by whatever amount soil absorption is increased by the action of the tile. However, the influence of tile on run-off will develop gradually and appreciable effects will be long delayed because the installation of such drains will proceed slowly.

Artificial drainage may increase the rate of run-off by increasing the number of outlets and thereby shortening the time period during which run-off occurs. However, the decrease in run-off due to increased absorption by the drained soil may more than compensate for the extra outlets.

The only important conclusion which has been reached relative to the effect of artificial drainage on run-off is, that when heavy rainfall occurs or when large quantities of snow melt rapidly, artificial drains may operate to increase the rate of run-off when areas drained are for any reason impervious to water, that is, when the ground is frozen or is saturated. Such increase in rate of run-off will increase flood heights along watercourses of insufficient capacity. Observa-

tions seem to indicate, however, that in the Red River valley open drains do not materially increase run-off caused by melting snows in the spring, because a large majority of drains are completely filled or badly obstructed by snow and ice and do not begin to function until several days after the snow on the watershed has melted. Under such conditions run-off collects and flows in natural depressions or channels without being affected to any considerable extent by artificial drainage.

EVAPORATION AND TRANSPIRATION.

By far the greater part (between 85 and 98 per cent) of precipitation on the Red River watershed is disposed of by evaporation and plant transpiration. As run-off comprises only the remainder of the precipitation those processes largely govern total run-off. Large quantities of water evaporate from the soil and from water and snow surfaces. Annual evaporation from the soil has not been determined definitely but under ordinary conditions this alone is probably as great as annual run-off. The process, however, goes on at a much slower—although more uniform—rate than does run-off, so its relative effect is small when the run-off rate is high.

The rate of evaporation from shallow water near Grand Forks has been measured and recorded by Prof. E. F. Chandler for the period 1905 to 1914. The results have been used in computing the probable evaporation from lakes and reservoirs. Table 10 shows the mean monthly evaporation and the mean monthly temperature for the period 1905–1914.

TABLE 10. *Mean monthly temperature and evaporation at University (near Grand Forks), N. Dak.*

Month.	Mean temperature.	Mean evaporation.	
	° F.	*Inches.*	*Billions of cu. ft. per sq. mi.*
January	4.0	0.40	0.0009
February	7.3	.60	.0014
March	22.8	1.20	.0028
April	44.5	3.22	.0075
May	52.1	4.12	.0095
June	65.0	4.94	.0114
July	67.5	5.78	.0134
August	65.5	4.60	.0107
September	57.7	3.63	.0084
October	45.9	2.11	.0049
November	27.6	.63	.0015
December	11.3	.40	.0009

The evaporation figures for April to November, inclusive, are results of observations by Prof. E. F. Chandler, 1905 to 1914; those for December to March are estimates made from available data relating to evaporation during winter months.

The figures deduced by Meyer,[5] as to evaporation from snow and ice, agree very closely with the results of observations made by

[5] The Elements of Hydrology, Adolph F. Meyer.

Horton.[6] These authorities show that evaporation as high as 2.2 inches may occur during a month just before the snow and ice is changed into water. Snow melting slowly is subject to greater evaporation than snow melting more rapidly because of rains or high atmospheric temperatures.

ABSORPTION AND STORAGE.

Absorption by the soil, which is in effect a storage of water, affects run-off in two ways. In retarding the escape of water it decreases the rate of run-off by increasing the time required for water to reach drainage outlets, and the amount of run-off by increasing opportunity for evaporation and plant transpiration. Percolation also tends to reduce run-off in much the same manner as does absorption. In the spring the amount of percolation depends upon the condition of the ground when thaw begins. It has been found where the ground, even if frozen, is not saturated, and where water or slush covers it for a time, that a surprisingly large amount of water will seep away. Thus the percolation factor, the dryness of the ground, and the depth to which it was frozen before being covered with snow may affect run-off very materially.

The effect of storage in lakes, ponds, and reservoirs is similar to that of storage by soil absorption. The stored water is delayed in reaching drainage outlets, and thus greater opportunities for evaporation and transpiration are afforded.

RELATION BETWEEN PRECIPITATION AND RUN-OFF.

For each of those watershed areas on which precipitation and run-off records are coextensive the probable effect of extreme precipitation conditions was determined. Moreover, various relations which are more or less indefinite were indicated by data compiled. Thus certain data on precipitation were adapted for use to a limited extent in connection with other data in estimating run-off for all the watershed areas listed in Table 5. As the run-off records for the watershed above Grand Forks cover a much longer period than is covered by records for any other area the relation of precipitation to run-off was investigated in considerable detail for that watershed.

ANNUAL AND MONTHLY PRECIPITATION AND RUN-OFF.

For the period 1882 to date annual and monthly precipitation records are available for all the watershed areas on which records have been kept of the run-off. On four watersheds, namely, Red River above Grand Forks, Red River above Fargo, Red Lake River above Crookston, and Thief River above Thief River Falls, the ratio

[6] Monthly Weather Review, U. S. Department of Agriculture, February, 1914.

of annual run-off to annual precipitation was computed. The data for the area above Grand Forks are shown in figure 16. On that watershed the run-off in 1897 was maximum both in depth (3.2 inches) and in percentage of annual precipitation (14.3 per cent). In 1916, when maximum recorded annual precipitation occurred, the run-off (3.1 inches) was nearly maximum, but the percentage of precipitation (11.2 per cent) that appeared as run-off was less

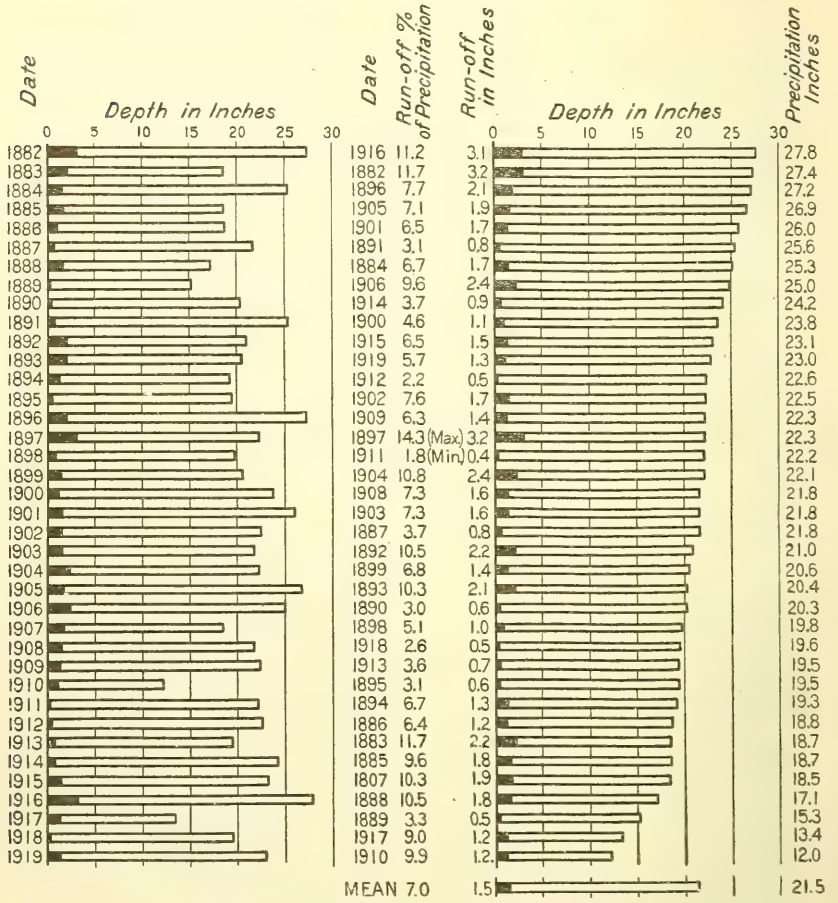

FIG. 16.—Annual precipitation and run-off on Red River of the North watershed above Grand Forks, N. Dak.

than for 1897. The run-off during 1897 was increased by the heavy precipitation of 1896, by maximum depth of snow on the ground in March, 1897, and by extremely heavy monthly and storm precipitation during July, 1897.

Probable future maximum run-off as estimated from a study of all available data for the four watersheds mentioned above is indicated in Table 11. It is improbable, however, that run-off equiva-

lent to the percentages shown in the table will occur during any year when annual precipitation is maximum in depth.

TABLE 11.—*Probable maximum annual run-off.*

Streams.	Station.	Drainage area.	Ratio of annual run-off to annual precipitation.
		Sq. mi.	*Per cent.*
Red River	Grand Forks, N. Dak	25,755	15
Do	Fargo, N. Dak	6,435	15
Red Lake River	Crookston, Minn	5,320	25
Thief River	Thief River Falls, Minn	1,080	25

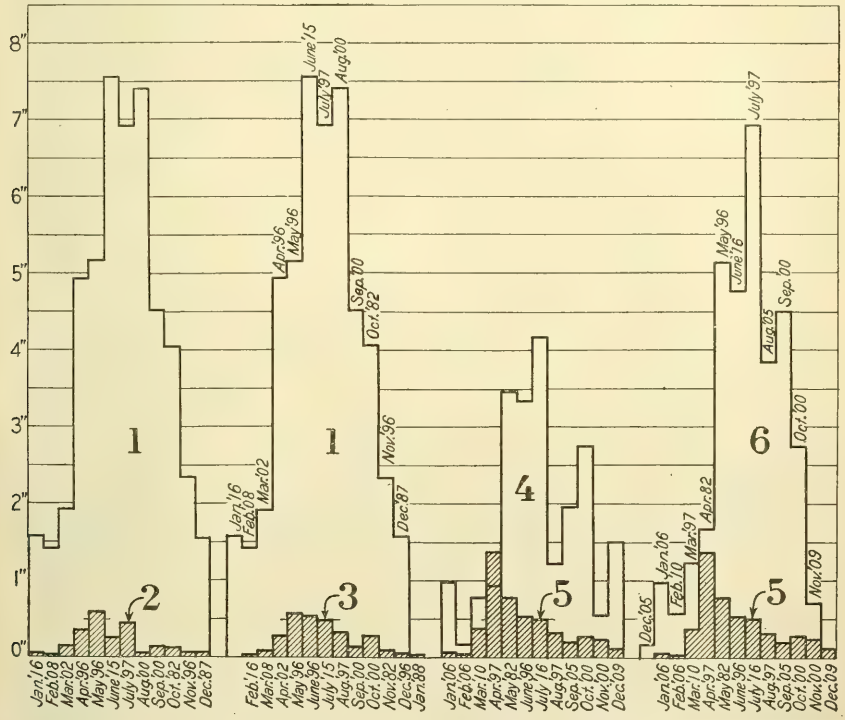

FIG. 17.—Precipitation and run-off, Red River of the North watershed above Grand Forks, N. Dak., for selected months, 1882–1919. 1, Maximum monthly precipitation; 2, run-off during months of maximum precipitation; 3, monthly run-off immediately following maximum monthly precipitation; 4, precipitation during months of maximum run-off; 5, maximum monthly run-off; 6, monthly precipitation immediately preceding maximum monthly run-off.

Investigation shows conclusively that run-off can not be determined by considering it merely as a fixed percentage of precipitation. The part of precipitation that supplies demands of evaporation and plant transpiration is much greater and is more nearly uniform in quantity from year to year than is the part that goes into run-off. For the watershed above Grand Forks, comparisons of annual run-off and annual precipitation are shown in figure 16. Monthly distribution

of precipitation and run-off are shown in Tables 6 and 4. During the period 1882 to 1919, maximum monthly precipitation occurred 8 times in May, 13 times in June, 11 times in July, 5 times in August, and once in September. Maximum precipitation for a single month during the 38-year period occurred in June, 1915. June is recorded also as the month having the highest mean monthly precipitation during the period. For this same period the maximum monthly run-off occurred once in March, 24 times in April, 4 times in May, 3 times in June, 4 times in July, once in August, and once in October. Maximum run-off during a single month occurred in

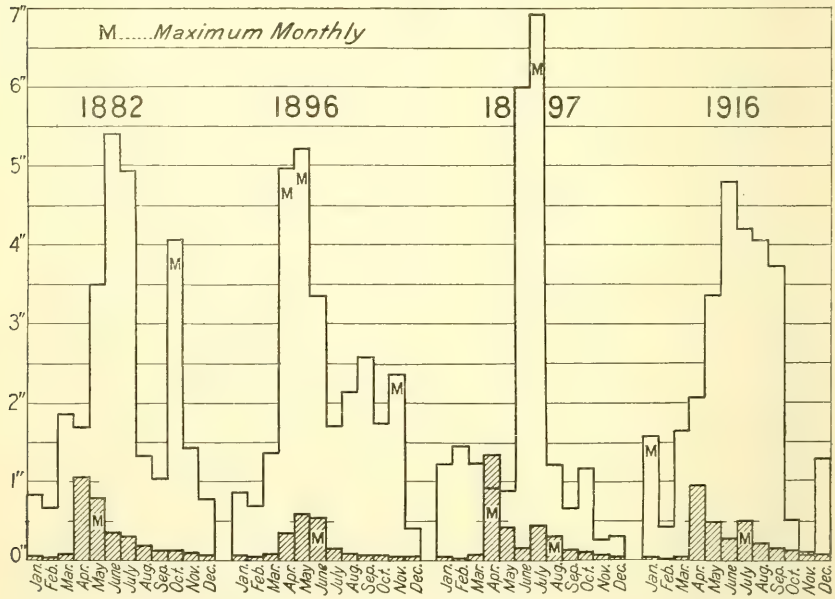

FIG. 18.—Monthly precipitation and run-off, Red River of the North watershed above Grand Forks, N. Dak., for 1882, 1896, 1897, and 1916.

April, 1897, while the month having the highest mean monthly run-off for the period also is April. Thus the records show June to be the month of greatest precipitation, and April the month of greatest run-off.

Various combinations of maximum monthly precipitation and run-off as recorded for the watershed above Grand Forks for the period 1882 to 1919, are shown in figure 17. Quantities of a similar kind for 1882, 1896, 1897, and 1916 are shown in figure 18. These diagrams indicate that during the period of April to November, inclusive, excessive monthly precipitation tends to produce high run-off during the next following month, and that the excessive precipitation is not reflected to any marked extent in the run-off for the same month in which such precipitation occurs.

RUN-OFF DUE TO STORM PRECIPITATION.

Only casual examination of the data is required to make it apparent that storm precipitation during summer months often has marked effect on run-off in the Red River watershed. The effect is relatively greater and is more apparent on small watersheds of tributary streams than on large areas, because the most intense storm precipitation occurs on comparatively small areas. In figure 19 the precipitation during four summer storm periods, each on a different

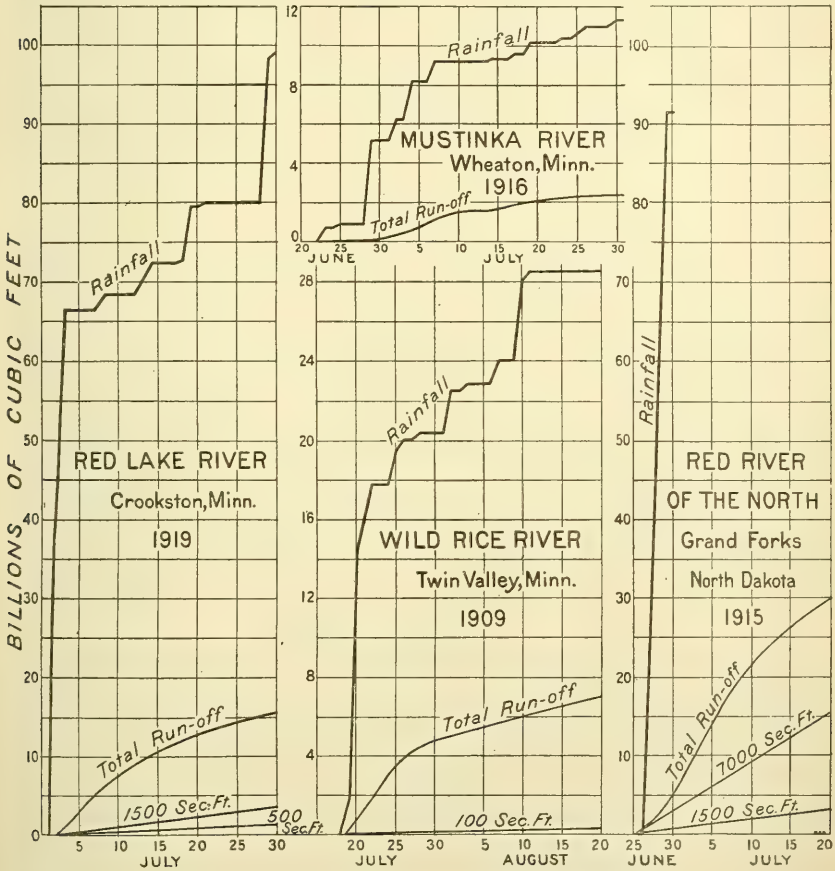

FIG. 19.—Accumulated storm rainfall and run-off.

watershed, is indicated in comparison with run-off which followed the storms.

On watersheds of 10,000 square miles or less, storm precipitation sometimes causes maximum run-off; but on the larger watersheds, such as that above Grand Forks, spring run-off due to melting snow is greater. Accordingly, figure 19 as well as other data on storm precipitation and summer run-off have been used largely in estimating probable maximum run-off for the smaller watersheds (see Table 5).

While figure 19 does not alone form sufficient basis for estimating maximum future run-off, yet the relations existing between volumes and intensities of precipitation and run-off, time periods, and areas are of importance in estimating future run-off which may result from summer storms.

ESTIMATES OF PROBABLE RUN-OFF.

In Table 5 are shown the estimated rates of run-off for various subdivisions of the Red River watershed. The basis for these estimates is all available run-off records for annual, monthly, and daily periods, and for flood periods during spring and summer seasons, as well as data on precipitation and the results of a study of the various other conditions that affect run-off. As may be noted from Table 5, the rates of run-off shown are not expected to occur in such relation with respect to time that the excessive flow from all subdivisions will concentrate in the outlets.

Frequently, in connection with engineering reports on undertakings similar to the Red River project, certain formulæ or equations are developed or equations previously evolved are adopted for use in estimating run-off. In the present instance, however, each watershed is a problem of itself and any attempt to calculate run-off for the larger watersheds (say those of more than 200 square miles) by formulæ is likely to give results which would be quite unreliable owing to the wide variation of the influencing conditions and to the difficulty of assigning definite values to them. Accordingly no formula, equation, or curve has been developed and none is to be recommended.

RUN-OFF FROM SMALL WATERSHEDS.

For small watersheds, containing less than about 200 square miles, the size of watershed drained is usually the dominating feature in determining the rate of run-off. For such areas a run-off formula in which the area of watershed is the principal factor may give satisfactory results if care and judgment are used in applying the formula.

TABLE 12.—*Estimated run-off, per square mile, from small watersheds.*

Area (square miles).	Minnesota.[1]	North Dakota.[2]	Area (square miles).	Minnesota.[1]	North Dakota[2]
	Cu. ft. per sec.	*Cu. ft. per sec.*		*Cu. ft. per sec.*	*Cu. ft. per sec.*
1	12.0	.....	25	8.7	6.7
2	11.2	.....	30	8.5	6.6
3	10.7	.....	40	8.3	6.4
4	10.4	13.4	50	8.1	6.2
6	10.0	11.8	75	7.8	5.9
8	9.7	11.2	100	7.7	5.8
10	9.5	10.0	150	7.3	5.3
15	9.1	8.4	200	7.0	5.1
20	8.9	7.7			

[1] By J. T. Fanning, 1886. [2] By J. T. Stewart, 1907.

In preparing reports upon drainage projects in the Red River Valley, J. T. Fanning[7] (in Minnesota), and John T. Stewart[8] (in North Dakota), estimated run-off by a method in which the size of watershed is the principal variable considered. Their conclusions, as recorded for areas up to 200 square miles, are shown in Table 12.

CONCLUSIONS REGARDING RUN-OFF.

Relative to seasonal variations of run-off, the study made by the Bureau of Public Roads indicated two important conclusions as follows:

1. No combination of storm and monthly precipitation is likely to occur from May to October which will cause the Red River to overflow below Wahpeton.
2. No storm precipitation will cause excessive run-off and floods in any portion of the watershed from November to March, when the prevailing temperature is low.

These two negative conclusions may be stated positively thus: Excessive precipitation may cause floods on any of the streams from May to October except along the channel of the Red River below Wahpeton. Rapidly melting snow, or a combination of precipitation and melting snow, may cause floods along any of the streams in the Red River watershed during March or April.

There is nothing to indicate that conditions as to rate or volume of run-off are undergoing any permanent change in the Red River Valley. Rather it seems probable that the future run-off during any long-term period will be subjected to seasonal and periodical fluctuations as great as any that have occurred in the past.

THE FLOOD SITUATION.

Serious floods caused by rapid melting of snow and rain occur in early spring at intervals of from 1 to 15 years along the Red River below Wahpeton, N. Dak. These floods affect land and property in North Dakota and Minnesota, and in Manitoba, Canada.

During the period May to October local floods are caused by local storms which may cause very heavy rainfall over areas of 6,000 square miles or less.

SPRING FLOODS.

Just after the annual spring thaw the run-off is sometimes sufficient to overflow the outside high banks of the channel. At such times extensive areas of land are flooded. As the land along the stream is flat

[7] Report of Commissioners, "Red River Valley Drainage," Crookston, Minn., 1886 (out of print).

[8] Bulletin 189, Office of Experiment Stations, U. S. Department of Agriculture, May, 1907 (out of print).

and nearly level the flood water has very little current. Also, owing to the wide extent of the flat, level topography the flood depth is not great even when very large quantities of water overflow. These floods cause no damage to the land itself and a few generations ago, before agricultural development had begun in the valley, the floods were of no consequence. At present an extreme flood such as that of 1897 (see Pl. III, fig. 1), would damage much property, interfere with transportation, destroy live stock, and might cause loss of human life. Thus without increase in height or frequency of floods the possibilities of serious damage increases as the country develops and as population increases. A flood late in March may delay the preparation of the land and seeding long enough to greatly reduce yields, particularly of wheat, or may make it impossible to sow the lower portions of the fields at anything like the proper date. These spring floods are also important carriers of rank growing weeds of the river valleys.

A feature of the Red River which has an important bearing on spring floods is its northward flow through a region of low winter temperatures and heavy ice. Spring thaws begin in the upper portions of the watershed and move gradually downstream, causing run-off from large areas to reach lower portions of the river when the winter ice is breaking up and beginning to move along the lower channel. The ice lodges against trees and other obstructions which partially fill the high-water channel of the stream. (See Plate III, figs. 2 and 3.) This retards the current and reduces materially the discharge capacity of the stream. Chandler[9] states, relative to retardation of flow by ice, that it has been found by measurements that during early spring floods "on some days * * * the water has been 2, 3, and even 6 and 7 feet higher than would have been necessary to discharge the same number of gallons per day later in the season when there is no ice retardation * * *."

SUMMER FLOODS.

Throughout its entire length below Wahpeton the capacity of the Red River channel is sufficient to carry the average summer run-off of the watershed. Below the mouth of the Sheyenne River the capacity is greater than is necessary for average flow and is sufficient to carry the most extreme summer run-off likely to be caused by storm precipitation. Above the mouth of the Sheyenne River maximum summer run-off slightly exceeds the capacity of the waterway usually considered as being the stream channel but it does not overflow the outside high banks of the actual high-water channel of the river. At and above Fargo some flooding occurs within the high banks of the channel during summer months, seriously affecting highway traffic, city water, sewer facilities, and property on low

[9] "The Floods of the Red River Valley," Elwyn F. Chandler, The Quarterly Journal of the University of North Dakota, Vol. VIII, No. 3, April, 1918.

B. P. R.-D-4134

FIG. 1.—LOOKING ACROSS RED RIVER OF THE NORTH FROM MOORHEAD, MINN., DURING 1897 FLOOD.

B. P. R.-D-3578

FIG. 2.—LOOKING ACROSS AND DOWN THE RED RIVER OF THE NORTH AT BEND EAST OF WILD RICE, N. DAK., DURING THE LOW FLOOD OF MARCH, 1920. NOTE HOW TREES IN CHANNEL OBSTRUCT THE FREE FLOW OF WATER.

B. P. R.-D-3595

FIG. 3.—LOOKING DOWN THE RED RIVER OF THE NORTH FROM THE GREAT NORTHERN RAILWAY BRIDGE AT FARGO, N. DAK., MARCH, 1920. NOTE HOW TREES IN CHANNEL CATCH DRIFT AND DÉBRIS AND INTERFERE WITH THE FREE FLOW.

B. P.R.-D-1919

FIG. 1.—TYPICAL VIEW OF CHANNEL OF BOIS DE SIOUX RIVER SHOWING CONDITION OF CHANNEL BETWEEN WHITE ROCK, S. DAK., AND MOUTH OF RABBIT RIVER BELOW FAIRMOUNT, N. DAK., OCTOBER, 1918.

B. P. R.-D-4135

FIG. 2.—LOOKING UP RED RIVER OF THE NORTH FROM FRONT STREET BRIDGE, FARGO. N. DAK., JULY, 1916.

B. P. R.-D-3633

FIG. 3.—NORTH BROADWAY HIGHWAY BRIDGE NEAR FARGO, N. DAK. TYPICAL OF HIGHWAY BRIDGES BETWEEN FARGO AND GRAND FORKS. ON MARCH 28, 1920, THE WATER WAS 7 FEET ABOVE THE FLOOR OF THIS BRIDGE. THE BRIDGE RAILING FOLDS DOWN ON TOP OF THE BRIDGE. APRIL, 1920.

land along the stream; but no Red River overflow occurs below Wahpeton on land outside the real high-water channel of the stream during the crop-growing season. The land adjacent to the river that is overflowed is flooded by water from the tributaries of the Red, or by water which comes from rains.

FLOOD RECORDS.

During the last 40 years, the period for which definite records are available, the Red River at Grand Forks has risen above flood stage (elevation 819.5, stage 40 feet, U. S. G. S. gauge) seven times, viz, 1882, 1883, 1893, 1897, 1904, 1916, and 1920, each time in the spring soon after the annual spring thaw. Only in one case did high stages occur in two consecutive years (1882 and 1883). The longest period between flood stages was 12 years (1904–1916). Elevations and dates of high and low river stages at three stations, Fargo and Grand Forks, N. Dak., and Emerson, Manitoba, are shown in Table 13.

TABLE 13.—*Elevations and dates of flood crests and low-water stages.*

Year.	Fargo, N. Dak. (flood stage 887.5).		Difference (Distance 155 miles).		Grand Forks, N. Dak. (flood stage 819.5).		Difference (Distance 143 miles).		Emerson, Manitoba[1] (flood stage 779.5).	
	Date.	Elevation.	Days.	Feet.	Date.	Elevation.	Days.	Feet.	Date.	Elevation.
1882	Apr. 11	899.2	10	70.2	Apr. 21	829.0		38.9		790.1
1883					Apr. 28	820.1				
1893					Apr. 24	825.0		35.2		789.8
1897	Apr. 7	901.5	3	71.8	Apr. 10	829.7	12	39.1	Apr. 22	790.6
1902	Mar. 29	871.8	2	66.4	Mar. 31	805.4	4	26.9	Apr. 4	[2] 778.5
	Sept. 20	869.2	4	88.4	Sept. 24	780.8	6	30.8	Sept. 30	[2] 750.0
1903	Apr. 6	875.7	5	68.2	Apr. 11	807.5				
	Oct. 12	870.3	2	80.2	Oct. 14	790.1				
1904	Apr. 20	883.1	7	63.0	Apr. 27	820.1		34.1	([3])	786.0
	June 28	876.6	3	82.9	July 1	793.7				
1905	Mar. 31	871.3	6	74.3	Apr. 6	797.0				
	May 17	880.2		74.7	May 16	805.5				
1906	Apr. 9	877.3	9	61.8	Apr. 18	815.5				
	July 5	874.5	1	80.3	July 6	794.2				
1907	Mar. 30	891.6	8	72.3	Apr. 7	819.3				
	June 17	881.1	1	81.2	June 18	799.9				
1908	Apr. 5	875.7	6	63.4	Apr. 11	812.3				
	June 13	876.5		79.1	June 13	797.4				
1909	Mar. 30	874.8	9	78.8	Apr. 8	796.0				
	Aug. 12	871.4	5	74.6	Aug. 17	796.8				
1910	Mar. 19	884.9	3	74.7	Mar. 22	810.2				
	Oct. 29	867.4	7	84.9	Nov. 5	782.5				
1911	Apr. 11	870.5	4	81.8	Apr. 15	788.7				
1912	Apr. 8	872.2	1	80.0	Apr. 9	792.2				
	May 14	872.4		84.3	May 14	788.1	2	35.6	May 16	752.5
1913	Apr. 15	871.8		65.7	Apr. 8	806.1	3	30.6	Apr. 11	775.5
	July 8	873.7	4	87.1	July 12	786.6	4	36.2	July 16	750.4
1914					Apr. 9	791.9	8	33.6	Apr. 17	758.3
	May 2	875.5	3	83.8	May 5	791.7				
	June 12	877.7	5	80.0	June 17	797.7	2	38.4	June 19	759.3
1915	Apr. 9	887.2	2	88.6	Apr. 11	798.6	2	38.0	Apr. 13	760.6
	July 2	888.2	1	77.9	July 3	810.3	6	40.3	July 9	770.0
1916	Apr. 6	892.1	11	71.6	Apr. 17	820.5	7	33.8	Apr. 24	786.7
	July 12	889.4	2	85.8	July 14	803.6	5	38.8	July 19	764.8
1917	Apr. 3	886.2	3	74.3	Apr. 6	811.9	5	35.6	Apr. 11	776.3
	Aug. 28	869.8	5	86.8	Sept. 2	783.0	3	35.6	Sept. 5	747.4
1918	Mar. 30	871.8		81.0	Mar. 28	790.8	3	31.7	Mar. 31	759.1
	Sept. 20	869.8		85.9	Sept. 20	783.9	1	36.4	Sept. 21	747.5
1919	Mar. 24	872.8	10	76.0	Apr. 3	796.8	6	28.5	Apr. 9	768.3
	July 5	870.3	4	68.5	July 9	801.8	3	36.6	July 12	765.2
	Sept. 19	868.9		83.7	Sept. 19	785.2		36.0	Sept. 19	749.2
1920	Mar. 27	885.5	2	65.1	Mar. 29	820.4	10	40.8	Apr. 8	779.6

[1] Emerson gauge established May, 1912. [2] Datum uncertain. [3] Pembina.

Only two of the spring rises have resulted in serious floods throughout the entire valley; these occurred in April, 1882, and April, 1897, the latter being the maximum for which reliable records are available. The floods of 1893 and 1904 were more serious between Grand Forks and the international boundary than in other parts of the valley. The 1916 flood was most serious in the vicinity of Fargo and in upper portions of the valley, but it was of slight consequence at and below Grand Forks.

With regard to floods along the part of the river within the United States, records prior to 1880 are vague because no systematic method for recording gauge heights had been in use before that time. Information as to floods prior to 1860 is merely legendary. According to legend a flood occurred in 1852 which was from 1 to 10 feet higher than the 1882 flood at and below Grand Forks. Reliable records of floods since 1826 at Winnipeg, Manitoba, are available. The extreme floods there occur in May, nearly a month later than at Grand Forks, and are caused by fortuitous occurrence of high stages in the Red River and the Assiniboine River, which joins the Red within the city of Winnipeg. The maximum flood recorded at Winnipeg crested May 22, 1826, about 15 feet above the ordinary flood height in that locality. A flood 1½ feet lower crested May 22, 1852, and stages about 4 feet lower than that of 1826 are said to have occurred in 1776, 1790, and 1809. The highest flood since 1852 occurred in 1882 when the crest was 11 feet lower than in 1826. The crest of the flood of 1882 in the Red River passed Winnipeg several days before that of the Assiniboine reached the junction of the streams; thus a greater flood was averted. Considering these records for the lower river it appears probable that in 1852 a flood higher by one or more feet than that of 1882 occurred along the river at and below Grand Forks.

The records indicate that a serious flood may occur in any year; that the probable frequency is once in 15 years; and that the probable longest period without a flood is 30 years.

THE LAKE TRAVERSE—BOIS DE SIOUX—RED RIVER CHANNEL.

The Red River of the North is formed at Breckenridge, Minn., by the junction of the Bois de Sioux and Otter Tail Rivers, and follows a sinuous course to the north for about 394 miles to the international boundary; thence it continues to Lake Winnipeg. The Bois de Sioux River rises in Lake Traverse, the total length of the combined watercourse from the upper end of Lake Traverse to the Canadian line being 456 miles, which is approximately twice the distance between the two points as measured in a straight line. (See fig. 1.) The stream flows northward through the center of the bed of the ancient glacial Lake Agassiz, the land on both sides being very flat for some dis-

tance back from the banks. The fall along its course is for the most part slight and somewhat variable. Along the Bois de Sioux the fall is about 0.3 foot per mile; from Breckenridge to Fargo, about 1 foot per mile; and from Fargo to the Canadian line from 0.6 to 0.3 foot per mile. (See fig. 2.)

The channel of the upper Bois de Sioux is small and poorly defined (see fig. 4 and Plate IV, fig. 1), but in the vicinity of Breckenridge the banks are between 20 and 25 feet high, and from 100 to 200 feet apart. At this point there is a further increase in size due to the entrance of the Otter Tail, and from Breckenridge on for the greater part of its length the stream has an inner or low-water channel with banks of varying height, with one or more terraces on each side which bring the outer banks up to or slightly above the level of the adjacent land. The outer banks, in places on the lower part of the river, are from 1,000 to 1,200 feet apart.

The course is extremely crooked for most of its length, with many loops, bends, and side channels. The channel often doubles back upon its course and flows a considerable distance without gain in the general direction of flow. Over the greater part of its length the channel—especially the outer flood channel—is badly obstructed by trees and brush (see Pl. IV, fig. 2) and many buildings, fences, and other structures are situated within the outside banks. Many of the county wagon bridges have been built on the inner banks, spanning only the low-water channel (see Pl. IV, fig. 3); at flood stages these are either washed out or completely covered, thus forming additional obstruction to flow.

Owing to the slight fall in the stream bed and the fact that the slope decreases downstream as more water is added, the velocities of flow are small and channel erosion is comparatively slight. The stream under these conditions has not a channel of sufficient capacity at all points to carry the volumes of water present at high stages, and the situation is rendered the more acute by the obstructed state of the channel. As a result, heavy run-off from the watershed causes the stream entirely to fill the channel and spread widely over the contiguous country.

The upper part of the Bois de Sioux has practically no channel (Pl. IV, fig. 1) and at times of high water the adjacent land to the west becomes a part of Lake Traverse. The land to the east rises sharply a short distance from the stream. Farther down, the channel gradually develops until at a point about 10 miles upstream from Breckenridge it attains a capacity of 2,000 second-feet (see fig. 2 and fig. 4). At Breckenridge there is a sharp increase in slope and size of channel which gives a capacity of about 4,000 second-feet within the inner banks and about 8,500 second-feet for the entire channel. From Breckenridge to the international boundary there is

a continuous increase in size of channel of the Red River and a decrease in the general slope of the channel, broken by short stretches of greater fall (see fig. 2).

When the water in the river reaches a stage of 23 feet on the gauge maintained by the United States Weather Bureau at Moorhead, Minn., the water starts to overflow the inner banks and reaches some of the lower lying road grades, buildings, and bridges—the channel between the mouth of the Dakota Wild Rice River and the mouth of the Sheyenne River will easily carry 6,000 second-feet. A rise above 23 feet causes the overflow of low areas within loops of the river and parts of the city of Fargo which lie but slightly above the banks of the lower-water channel. Even at stages as high as 35 feet at Fargo no extensive areas of land are flooded. Below the mouth of the Sheyenne River the channel of the Red River will carry 12,000 second-feet, and from the mouth of the Buffalo to Grand Forks 15,000 second-feet can be passed without overflow. Below the mouth of the Red Lake River at Grand Forks the channel is considerably larger than above, and in the stretch between that point and the international boundary, along which the slope constantly diminishes, are found the sections of maximum area (see figs. 2 and 4). This part of the channel will carry a volume of 25,000 second-feet without topping the outer bank.

It should not be presumed that the river when flowing at these maximum rates will entirely fill the channel for its whole length, or that greater volumes can not be carried at some points without overflow. The figures given refer to the approximate maximum volumes that can be passed through the various sections of the channel without overflow at any point along the river. Greater volumes can be carried at certain points, but even though the river remains within the banks at these points it will overflow either above or below. When flowing bank-full, on the other hand, the smaller sections pass more water than their size and the slope of the stream as a whole would indicate. This is due to the heading up of the water above the sections of small area, and the ability of the larger sections below to carry the same volume at lower stages, which gives an increased water-surface slope through the restricted portions. The capacity as calculated by Kutter's formula agrees very closely with actual discharge as indicated by stream-gauging records.

TRIBUTARY STREAMS.

In some respects the tributary streams are much like the Red River, the fall being slight in the lower parts of the channels. However, in their upper reaches the fall in most cases is much greater than in the Red. These streams rise outside the old lake boundary and flow from the east and west through the old beaches across the flat lake

bed and into the main river. In many cases they parallel the river for some distance before finding outlet. They have sinuous courses and the channels are more or less obstructed by vegetation. Many of them originally spread out as marshes over the flats along the Red River and had no definite channels for some distance. Some of these streams have been improved through the flat areas by artificial channels which carry the water coming down from the higher parts of the basin and also provide outlet for the drainage of the marsh lands. The flow in the lower parts of most of these tributaries is sluggish, and many are subject to overflows during heavy run-off. Overflow near the mouth is caused in some cases by backwater from the Red River.

EFFICIENCY OF THE NATURAL DRAINAGE SYSTEM.

The general condition of the natural streams of the watershed results, during periods of heavy run-off, in constantly augmented bodies of water coming down badly obstructed channels of small and constantly diminishing slope, piling up as they progress, overflowing stream banks, and finally all uniting in a common channel characterized by the same conditions of slight fall, obstruction to flow, and diminishing slope; all this resulting in the overflow of large areas of flat land along the main stream. A study of the various streams of the basin shows that, with the exception of those with relatively small contributing areas, the channels are or can be made sufficient to carry the run-off during the summer months without overflow. In cases of intense local storms over limited areas, serious damage has at times resulted from flooding during the summer, but where the drainage area involved is greater than about 6,000 square miles the extent of heavy precipitation and the concentration of the run-off is not great enough to cause damaging overflow. It is the spring run-off, resulting from melting snow and ice and the general spring rains, that causes the floods which cover a large portion of the valley.

ARTIFICIAL CHANNELS.

Artificial drainage channels serve the double purpose of facilitating the movement of the flood waters to the natural channels and of providing outlet where natural drainage is lacking or inadequate. In the former capacity they provide a means for the rapid escape of the excess surface water during periods of snow melting and heavy precipitation, removing it quickly to the natural channels. In swamp regions they remove the permanent excess of water, making possible the agricultural development of the land. They are, in short, an elaboration of the natural drainage system of the watershed.

The Red River watershed includes large areas of land that originally were sloughs, marshes, and swamps. These are of two classes with respect to location and origin of swampy condition; namely, those lying near the Red River in the bed of the glacial Lake Agassiz, and those outside the old beaches and situated at a considerably higher elevation. The former owe their existence as marsh land to the spreading of the larger streams as they came from the higher ground into the flat lake bed, and to small creeks, blind coulees, and general surface flow on to the almost level land bordering the river. These swamp areas lie on both sides of the Red River for the greater part of its length and generally are free from timber. The second-named type of swamp results from insufficient outlet due to flatness and to natural barriers to stream flow in the form of ridges. Most swamps of this class lie in the eastern part of the watershed. Some the low pockets entirely surrounded by higher land, but for the most part they are swamps of comparatively wide extent and are permanently saturated. Direct precipitation, surface flow, and small streams constitute the source of their water. Lying as they do in the upper part of the watershed, no large streams traverse them as in the case of those in the lower levels. In fact, most of the larger streams which contribute to the swampy conditions below have their sources in these upper areas. These swamps, for the most part, originally were timbered, although in places there were considerable areas of open country and more has been cleared as drainage activities have progressed.

DRAINAGE DITCHES.

In studying the artificial drainage of the watershed the flat areas which form the old lake bed were considered separately from the upland areas. The lands included in the former class are those lying on both sides of the river inside the 1,050-foot contour (see fig. 1) from Lake Traverse to the north line of Richland and Wilkin Counties; inside the 1,000-foot contour from there to an east-west line through Fargo; inside the 950-foot contour from Fargo to an east-west line through Grand Forks; and inside the 900-foot contour from there to the Canadian boundary. The drains which serve these lowlands have but little fall and lie only slightly higher than the Bois de Sioux and Red Rivers which they enter either directly or through short reaches of natural streams. Consequently, they depend to a large extent for efficiency upon the conditions of river flow and are intimately connected with any project concerning the river. The upland systems, with greater fall and free-flowing outlets, are not directly concerned with the conditions below.

The wet lands along the main watercourse have been improved by enlarging and extending the channels of the larger streams, and by systems of open ditches. The most extensive work of this nature

has been done on the Minnesota side, where the greater part of the land along the river is now under cultivation although much improvement to drainage is still possible. Considerable drainage work has been carried out on the Dakota side also, but there still remain large areas of marsh land which are not used at all, or at best are used only as wild hay land or pasture. In Table 14 are shown, for each county involved, the areas of land lying within the limiting contours of the lowland country, the amount of low land within one-half mile of artificial drains, and the percentage of land thus served. This table shows clearly how much greater has been the progress of artificial drainage development on the east side of the river than on the west. Many of the marshes in the flats along the river are brackish, as is also the ground water under them.

TABLE 14.—*Artificial drainage of Red River lowlands.*

County.	Total area of lowland.	Area within one-half mile of drains.		County.	Total area of lowland.	Area within one-half mile of drains.	
Minnesota:	*Sq. mi.*	*Sq. mi.*	*Per cent.*	North Dakota:	*Sq. mi.*	*Sq. mi.*	*Per cent.*
Traverse	307	184	60.0	Richland	835	55	6.6
Grant	190	45	23.7	Cass	937	176	18.8
Wilkin	588	218	37.1	Traill	492	52	10.6
Clay	617	230	37.3	Grand Forks	639	22	3.4
Norman	509	224	44.0	Walsh	501	27	5.4
Polk	1,061	604	56.8	Pembina	730	143	19.6
Marshall	543	206	37.9				
Kittson	576	103	17.9	Total	4,134	475	11.5
				South Dakota:			
Total	4,391	1,814	41.3	Roberts	43	0	0

The workings of the drainage laws, through the arbitrary fixing of the extent, location, and channel sizes of ditch systems, have often hindered engineers in their efforts to design adequate means for relief. At times of flood in the Red River and in the lower parts of its tributaries, back water from these streams prevents the normal flow of water in the outlet ditches.

Very extensive drainage systems have been constructed in the higher parts of the watershed on the Minnesota side of the river. They furnish outlet through or around ridges, give adequate fall through flat areas, and provide means for lowering the water table in higher swamp regions. In many cases the immediate local drainage of the territory affected has been given attention; while in others only the general outlet channels have been provided, leaving the smaller local drains to be taken up as the development of the locality warrants. Very little drainage has been required in the uplands on the west side of the river north of an east-west line through Fargo.

The results of artificial drainage in the upper parts of the watershed have been generally satisfactory, although in some cases the

work has not been comprehensive enough to provide for extensions that have or may become desirable; moreover, proper attention to the outlet facilities has been neglected in some, and in others the design of the system has been faulty. Many of the early ditches were shallow, and too small to afford good drainage. The ditches that are now being constructed are generally deeper and larger, and are therefore much more efficient as drains. The snow and ice in the spring fill many of the drains, but there seems to be no way to overcome this difficulty.

Damaging floods have occurred in Thief and Roseau River basins at times of extraordinary storms such as that of July, 1919 (see fig. 12 and Table 9). A part of this area is extensively ditched, many of the land sections having ditches on two or three sides. Nevertheless at the time mentioned the ditches and streams overflowed, the water completely submerging large areas and doing great damage. The trouble seems to have been due, mainly, to the inability of the two rivers in their present condition to carry off the water brought to them through the artificial channels, and to some extent to the over-taxing of these artificial channels by the run-off from too large areas. Under normal conditions most of the land affected is free from damaging water.

The development of graded highway construction throughout the watershed has grown to be a somewhat important factor in the removal of run-off. As it has progressed, more and more attention has been given the proper drainage of road grades until at present practically no new construction is undertaken without provision for the removal of water which might prove injurious to the roads. The network of road ditches which is rapidly spreading over the entire watershed has a marked and increasing effect upon the rapidity with which the run-off from spring thaws and storms collects in the streams and drainage ditches and is a factor not to be neglected when considering the rates of run-off over the drainage basin. On the other hand, road embankments in some localities have interfered with drainage outlets.

TILE DRAINAGE.

Tile drainage has barely passed the experimental stage in the Red River Valley, but the practicability of this method of local drainage for the farm lands of this valley has been fully demonstrated by tests that have been carried on continuously since 1907 at the Minnesota State Experiment Farm at Crookston and by several private undertakings. The soil in which these tests have been made is typical of that occurring generally over the flat areas along the river and the results obtained are indicative of what may be accomplished throughout the low-lying lands. The private tile systems that have been installed have operated with varying degrees of success. It is doubt-

ful whether the design has been proper in all cases. The upland soils are of a lighter, more porous character, and the question of successful tile drainage is one of proper design and construction rather than of practicability.

The very dense soil of the lowlands takes water slowly. During wet seasons the soil often remains completely saturated and even submerged for considerable periods. The light slope of the land retards the surface flow and crops frequently are damaged through the presence of this excess water. Tile drains, properly placed, provide direct channels to the outlet. They rapidly remove the free water from the soil, thus quickly renewing its capacity for absorption and in time increasing the porosity of the soil above the drains, thereby accelerating percolation and the removal of excess water. Surface evaporation is decreased during dry periods, especially on cultivated lands. The net result of tile drainage, therefore, is a reduction of the bad effects of excessive moisture during wet periods and of deficient moisture at times of drought. In the uplands are many areas too wet to be cultivated that can be made arable by tile drainage. As the development of farming progresses, more and more of this higher-lying land will be improved by this means.

RECOMMENDED PLAN OF DRAINAGE.

The surveys and investigations revealed clearly that the securing of adequate drainage for the wet and overflowed lands in the valley of the Red River of the North requires that floods be either controlled or reduced in stage as much as possible and that adequate drainage ditches be provided to remove excess water rapidly from those lands which have insufficient natural drainage.

It was found that in the watershed of Lake Traverse and the Bois de Sioux River (see fig. 1), the conditions affecting drainage and flood control were such that the improvements in this section of the valley must be constructed as one project. However, in preparing the plans the effect of the recommended improvements upon the flood situation in the lower valley was given careful consideration. The work in the valley separates into three projects, which can be carried out separately or as one large project. These are the Lake Traverse-Bois de Sioux, the Red Lake-Red Lake River, and the Red River of the North projects.

LAKE TRAVERSE—BOIS DE SIOUX PROJECT.

SUMMARY OF RECOMMENDED WORKS.

The improvements recommended in the Lake Traverse-Bois de Sioux watershed are, briefly, the following:

1. A detention reservoir to be formed in Lake Traverse by the construction of an earth dam provided with spillway and outlet con-

trol and extending across the watercourse and the adjacent lowland near White Rock, S. Dak., and also an earth levee at the south end of the lake, near Browns Valley, Minn.

2. A new channel for the Bois de Sioux from the dam in Lake Traverse to a point near Wahpeton, N. Dak., where the natural channel will carry the water without flooding.

3. A system of ditches to provide for the drainage in the areas to be reclaimed by the project.

In addition it will be necessary to replace some of the present bridges with larger ones and to construct new ones at points where the operations would otherwise interfere with transportation.

These improvements are designed to relieve flood conditions, make possible the reclamation of the wet lands along the Bois de Sioux, and provide outlets for the drainage necessary to the development of this area.

DESCRIPTION OF WATERSHED.

Lake Traverse and the Bois de Sioux River, with their tributary watershed, include the south end of the bed of the glacial Lake Agassiz and the land adjacent to its shores. The nature of the topography and soil is a result of glacial action and subsequent natural processes as previously discussed. The soil is alluvium, composed of clay mixed with varying quantities of fine sand and organic matter, with occasional bowlders occurring in the vicinity of White Rock. It is fertile, and when drained and cultivated produces good crops of wheat and other small grains, potatoes, grasses, and vegetables and fruits adapted to the climate.

That part of the watershed lying in North and South Dakota, together with a strip approximately 30 miles wide just east of the Bois de Sioux and Lake Traverse in Minnesota, is prairie land. The only timber occurs in strips, varying in width from 100 feet to one-half mile, along the principal streams. The land is flat and rises in a gentle slope on both sides. Practically all the prarie land has been cultivated.

The eastern portion of the watershed, in Minnesota, was originally covered by forests. The topography is quite rough and there are many depressions, in some of which are found lakes while others are simply marshes. Over much of the area the timber has been cut and the lands cleared, until at present probably less than 10 per cent of this area is forested. The total area of the watershed above the junction of the Bois de Sioux with the Otter Tail, at Breckenridge, Minn., is 1,875 square miles.

Owing to the flatness of the land surface and to the limited quantities of water which the drainage channels have carried, the latter are poorly developed and are not large enough to carry off the excess of

B. P. R.-D-3097

FIG. 1.—CHANNEL OF BOIS DE SIOUX RIVER EAST OF FAIRMOUNT, N. DAK. WATER 4 FEET DEEP, 60 TO 120 FEET WIDE, DISCHARGE ONLY 42 CUBIC FEET PER SECOND. JULY, 1919.

B. P. R.-D-3632

FIG. 2.—LOOKING SOUTH ALONG EAST SHORE OF LAKE TRAVERSE. SITE OF PROPOSED DAM SOUTH OF WHITE ROCK, S. DAK., APRIL, 1920.

precipitation without overflow. Three conditions make additional surface drainage necessary: (1) Flat or nearly level land surface without natural drainage channels; (2) depressions in which water collects and stands because of lack of outlet; and (3) natural channels too small to serve properly the areas they drain. Heavy soils or other conditions make underdrainage necessary in many localities. The north shore line of Lake Traverse is not well defined (see fig. 3, sheets 2 and 3), and during high stages the lake overflows the land several miles to the north. Much of this land has been or is now cultivated and the remainder is used to some extent as hay land.

The present channel of the Bois de Sioux is entirely inadequate to carry the water that comes to it from Lake Traverse (see Pl. V, fig. 1). The cross sections (fig. 4) show that near Lake Traverse the stream has practically no channel. As one goes downstream the size of the channel gradually increases until at Breckenridge it is large and well defined. The Mustinka River, which drains 852 square miles, rises in the hills near Fergus Falls and flows south about 25 miles and then west and southwest to Lake Traverse. Practically all of the watershed of the Mustinka in Traverse County (see fig. 1) has been drained by ditches spaced approximately 1 mile apart. In that county the channel of the Mustinka has been dredged and straightened for a considerable portion of its course. The Rabbit River drains approximately 300 square miles lying north and west of the Mustinka. It enters the Bois de Sioux about 10 miles south of Breckenridge (see fig. 3, sheets 3 and 4). As shown in fig. 1, a considerable portion of its watershed has been drained by open ditches spaced 1 mile apart. From a point about 4 miles south of White Rock, S. Dak., north to Fairmount, N. Dak., there is a strip of land along the Bois de Sioux which is frequently overflowed. From Fairmount north to Breckenridge the lands are occasionally overflowed. At times serious damage is caused by water from the Wild Rice River in North Dakota breaking out of its banks, flowing east, and flooding the land between its channel and the Bois de Sioux. Similar conditions exist on the Rabbit River and Otter Tail River, which flood land southeast of Breckenridge.

As the channel of the Bois de Sioux is too small to remove the water which comes to it when heavy rains occur, much land is flooded and the drainage of the higher-lying lands is obstructed. The flood water drains off slowly through the inadequate watercourse or remains on the land until evaporated. In years when heavy rains occur during the summer months, the crops are seriously damaged or completely destroyed. This damage becomes more serious if preceded by a wet spring. Floods are frequently caused by the melting of snow in the spring. These spring floods cause some damage by interfering with farming operations and prevent planting at the proper time.

The information collected shows very clearly that the highest floods are those caused by melting snow, combined in some instances with rains at a time of the year when the ground is more or less impervious to water. However, the floods that have caused the greatest loss to crops have been those caused by heavy rains over the watershed during the period from May to August. The natural drainage is not capable of removing the run-off from heavy storms, such as occurred in 1916, in time to prevent flooding and serious damage to crops. In many instances where an attempt has been made to relieve this condition by constructing ditches, it has not been possible to secure a satisfactory outlet or the drains have been dug too shallow and too small.

THE PROBLEM.

In order to relieve the conditions just described, it is necessary either to provide channels of sufficient capacity to remove the run-off from storms and spring thaws without flooding or so to control this run-off that the drainage channels shall not be overtaxed. A combination of the two methods is recommended as most advantageous. A number of different plans for accomplishing these results were given careful study. No discussion will be given of the several plans considered but not adopted.

In reaching conclusions as to the conditions which must be met in planning the improvements extensive and detailed studies were made of all available precipitation and run-off records. These studies and the methods used in estimating requirements have been discussed, and only those phases that apply to this project in particular will be taken up here.

In planning for the drainage of this watershed provision has been made only for outlet drainage. Only those works have been included that will require joint action of the three States interested. Some suggestions are made as to lateral drainage, but it is believed that these local drains can be constructed most economically under the drainage laws of the State in which the drains are located.

THE DETENTION RESERVOIR.

The reservoir, by means of which it is proposed to control the run-off from the Lake Traverse watershed, would include that part of the present bed of the lake between Browns Valley, Minn., and the north line of sections 24 and 33, T. 128 N. Along this line, which is about 4 miles south of White Rock, S. Dak. (see Pl. V, fig. 2), it is planned to build the earth dam extending to high ground on both sides. The proposed sluiceway for controlling the outflow is located at the intersection of the dam with the Boise de Sioux channel, and the spillway for protecting the dam from damage by over-

flow is placed at the extreme east end. Both of these structures are to be of reinforced concrete. For the location, elevation, and dimensions of the dam see figure 3, sheet 2, and figure 4. A levee at the south end of the lake, near Browns Valley, will be necessary to prevent overflow into Bigstone Lake. A channel extending about 2 miles back into the reservoir is planned to facilitate flow to the sluiceway. The embankment of the railroad spur from Browns Valley to the grain elevator at the south end of Lake Traverse must be raised to avoid interruption of traffic by water in the reservoir. (See fig. 3, sheet 1.) On account of the navigation on Lake Traverse it is not permissible to lower the water surface of the lake artificially below elevation 972, the present low-water stage. As the breaking of the reservoir when full would cause a great flood and much damage to property and crops, it has been made of such dimension as will give a large factor of safety, and it will store the run-off from a storm much larger than any on the Red River of which we have a record.

RUN-OFF TO BE CONTROLLED.

Fairly complete precipitation records from about 1893 to date are available, as are also data (April, 1917, to date) from which the discharge of the Mustinka River into Lake Traverse can be computed, and for the discharge of the Bois de Sioux for 1919 and 1920. In addition there are some data relative to flood heights and a few measurements of run-off made in the watershed. Also, there is available considerable information in regard to run-off from other drainage areas in the watershed of the Red River. The records of discharge are shown in Table 3. In view of the paucity of actual flood discharge measurements it was necessary, in order to decide upon the probable run-off from the watershed under consideration, to establish some relation between precipitation and run-off.

In studying the available records of run-off, as shown in Table 3, it was found that by far the greatest run-off per square mile that has ever been recorded in any watershed tributary to the Red River occurred in the Wild Rice watershed in Minnesota as a result of the storm of July 21–23, 1909. (See Table 9.) Computations of monthly and annual run-off for the period July, 1909, to December, 1917, also show that the maximum monthly and half-yearly run-off measured during that period occurred on the Wild Rice River during 1909.

As the run-off from January to June, 1909, was not measured and a maximum year could not be estimated therefrom, the records from January to June, 1916 (showing maximum half-yearly run-off since 1909), and from July to December, 1909, were combined as though they had occurred in one year. The period January to June, 1916,

was selected because the heaviest run-off for the first six months of a year was recorded during that year. The precipitation for these periods is shown in figure 7. It will be noted that the heaviest precipitation occurred over the eastern and southern parts of the watershed, and that the precipitation diminished in intensity toward the northwest. It is thought that this combination, which includes the July, 1909, storm, will give a greater annual run-off than has ever actually occurred from the watershed of the Wild Rice River in Minnesota. A comparison of figures 6 and 7 shows that the combined precipitation is heavier than that which occurred on the Wild Rice watershed in 1896, the year of maximum recorded annual precipitation over the Red River watershed.

In computing quantities for which storage and outlet capacities must be provided in order to control the run-off, it is necessary to take into account the amount of evaporation from the water surface of the reservoir. Using figures shown in Table 10, these quantities were computed in billions of cubic feet for an area of 35 square miles, the area of the exposed water surface at elevation 979. Any rise above this elevation would cause only slight increase in the surface exposed. These quantities were deducted from the estimated inflow to the reservoir.

A study of the relation of the run-off to rainfall in the watershed of the Wild Rice and the Mustinka, which latter is the principal tributary to Lake Traverse, indicated that the ratio was approximately the same for both watersheds.

Available data indicated that the run-off per square mile from the Lake Traverse watershed might be expected to be as large as may occur from the Wild Rice watershed and that the monthly distributions during the year would be nearly the same. The Lake Traverse watershed is 1.6 times as large as that of the Wild Rice. Accordingly, the run-off from the Wild Rice for the period January to June, 1916, and July to December, 1909, was increased by 60 per cent; and to make allowance for the earlier spring in the Lake Traverse watershed, one billion cubic feet was transferred from April to March. The monthly evaporation from Lake Traverse was then deducted and the remainder was taken as the maximum amount of water for which provision must be made. Monthly and accumulated quantities thus estimated are as follows, stated in units of billions of cubic feet.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Monthly	0.13	0.06	1.24	2.83	2.47	3.10	7.83	3.76	0.88	0.28	0.51	0.34	23.43
Accumulated	.13	19	1.43	4.26	6.73	9.83	17.66	21.42	22.30	22.58	23.09	2.343	.....

This run-off represents conditions that would obtain if, after a wet spring, a storm such as occurred in 1909 should cover the Lake Traverse watershed.

The relation between the precipitation and run-off for the storm of July, 1919, was investigated in the same manner. It was found that approximately the same percentage of run-off occurred from this storm as from the storm of 1909 on the Wild Rice watershed; but as would be expected, on account of the greater storm area and less intensive precipitation, the run-off extended over a longer period of time. Plans were then worked out to control a run-off from the Lake Traverse watershed of 23.43 billion cubic feet, which constitutes the total run-off for the hypothetical maximum year. It is equivalent to 25 per cent of the maximum annual precipitation recorded on the watershed.

OPERATION OF THE RESERVOIR.

The reservoir is designed so to control the run-off from the tributary watershed that there will be no outflow from it in the spring before May 1 and, except under extraordinary conditions, the discharge through the sluiceway into the outlet channel will at no time exceed 1,000 second-feet. After May 1, such a flow can be accommodated by the river below without difficulty, except possibly at times of heavy storm run-off in the lower valley which may cause temporary high river stages. To relieve the lower channel under such conditions, the reservoir may be entirely closed for a period of at least 15 days at any time necessary, thus eliminating for such a period the flow from the Lake Traverse watershed.

The flow through the sluiceway, as planned, can be maintained at 1,000 second-feet under varying head, by regulating the gate opening, and at high reservoir stages over 2,000 second-feet can be discharged when necessary. It is proposed to place the spillway crest at elevation 983.0, which would give a storage capacity in the reservoir of 9.849 billion cubic feet when overflow begins. The spillway is planned to discharge at a rate of 2,000 second-feet when the water reaches elevation 985.0, which is 3 feet below the top of the dam. With the water at this elevation the reservoir would hold 12.035 billion cubic feet and the spillway alone would be discharging at a rate almost as great as the maximum rate of inflow which has been recorded. Table 15 gives the storage capacities of the reservoir at the different water surface elevations.

TABLE 15.—*Storage capacity for the proposed Lake Traverse detention reservoir south of White Rock, S. Dak.*

Contours.	Areas within designated contours.	Mean areas= volumes when 1 foot deep.	Total storage capacity above elevation 972.	Contours.	Areas within designated contours.	Mean areas= volumes when 1 foot deep.	Total storage capacity above elevation 972.
	Billions of sq. ft.	*Billions of cu. ft.*	*Billions of cu. ft.*		*Billions of sq. ft.*	*Billions of cu. ft.*	*Billions of cu ft.*
972	0.610	.....	0.000	980	.996	.986	6.764
973	.680	0.645	.645	981	1.017	1.007	7.771
974	.749	.715	1.360	982	1.037	1.027	8.798
975	.811	.780	2.140	983	1.065	1.051	9.849
976	.873	.842	2.982	984	1.092	1.079	10.928
977	.915	.894	3.876	985	1.121	1.107	12.035
978	.956	.936	4.812	986	1.149	1.135	13.170
979	.976	.966	5.778	990	1.243	.....	.....

The relations of inflow, storage, and outflow are shown in the mass diagrams of figure 20. It will be noted that, in these diagrams, the 15-day periods of no outflow have been taken in each case at a time when their effect in producing high reservoir stages would be greatest.

In diagram E of figure 20, the estimated mean annual run-off, "Inflow," was obtained by multiplying the mean monthly, 1909–1917, run-off of the Minnesota Wild Rice by 1.6, the ratio of the watershed areas, and deducting the loss by evaporation. The curve for the run-off of 1916, diagram A, figure 20, the year of maximum precipitation over the Lake Traverse watershed, was obtained by plotting as run-off for each month, 20 per cent of the precipitation over the watershed for the preceding month with the exception that 20 per cent of the total precipitation for December, 1915, and January and February, 1916, was plotted as the March, 1916, run-off, the January and February run-off being merely nominal. This ratio (20 per cent) of run-off to precipitation is the mean of those that prevailed immediately after the great storms on the Red River watershed as indicated by figure 19, and is considerably higher than is indicated for normal conditions by the rather meagre data available. Diagram E shows that with an outflow of 1,000 second-feet, starting May 1, the reservoir in a mean year would be brought to low stage by about the middle of June and that from that time on the outflow would at all times be less than 1,000 second-feet. The maximum storage required would be less than 2 billion cubic feet. In the case of run-off such as is estimated for 1916 (diagram A) all run-off prior to May 1 could be stored and the reservoir closed for 15 days during the summer, and yet the reservoir could be emptied by the middle of December. In that case there would be a maximum storage of 4.3 billion cubic feet, which would not raise the water above elevation 978.

In diagram B of figure 20, maximum spring run-off (January-June) was plotted in combination with the summer and fall run-off

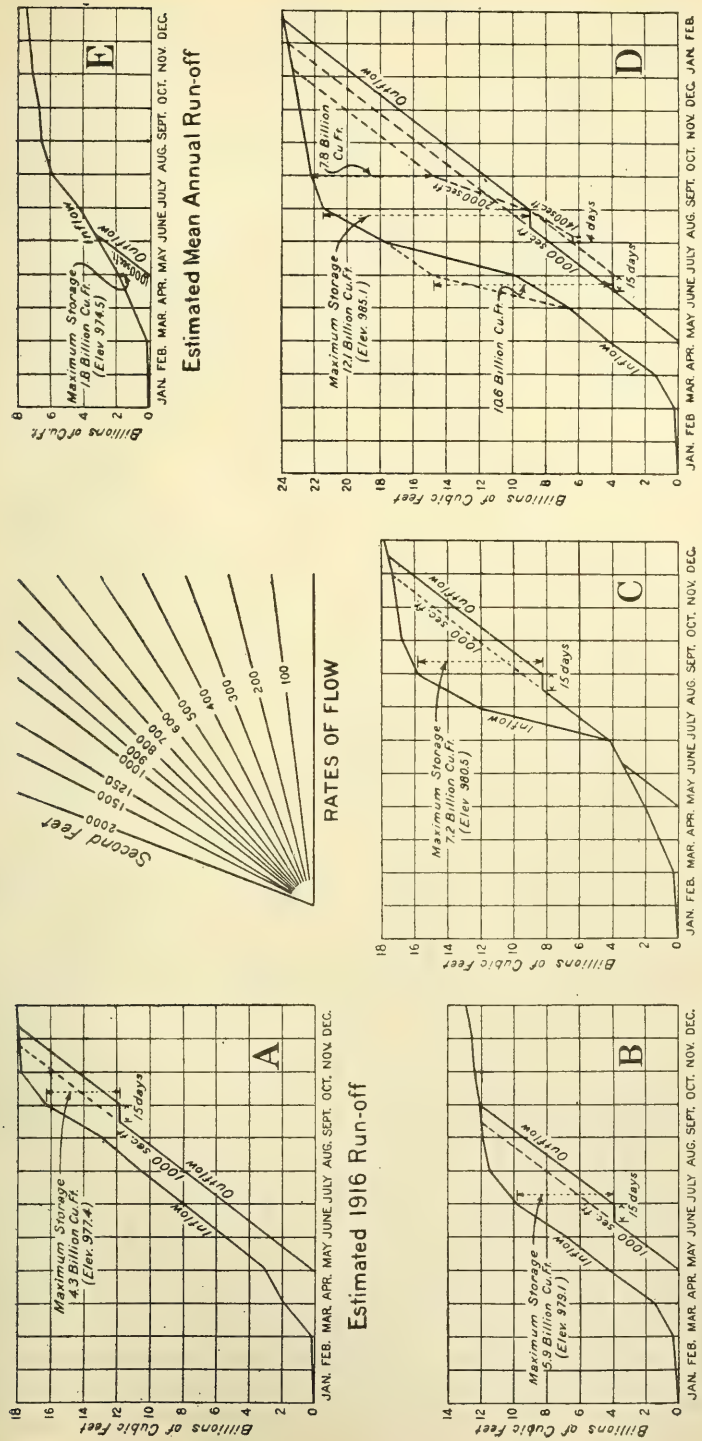

FIG. 20.—Relations between inflow, storage, and controlled outflow. Proposed Lake Traverse Detention Reservoir.

of the mean year. The maximum storage under these conditions is seen to be 5.9 billion cubic feet, at water elevation 979.1. The reservoir in this case would be empty by October 1.

In diagram C, figure 20, the run-off curve was made up of the spring run-off of the mean year (January-June) and the maximum summer and fall run-off (July-December). Maximum storage here is shown to be 7.2 billion cubic feet, at elevation 980.5. The reservoir would be empty by the middle of December.

In diagram D, figure 20, the most extreme conditions that may be expected are shown. The run-off plotted here is for the hypothetical maximum year as stated on page 64. This diagram shows that the maximum storage required in the most extreme case (that of closing the reservoir during the last 15 days of August) would be 12.1 billion cubic feet, if the rate of outflow were 1,000 second-feet continuously after May 1. However, before the water surface reached elevation 985.1 required for this amount of storage, the spillway alone would be discharging at a much greater rate than 1,000 second-feet, so that this stage would not be reached under these conditions and there would be a minimum freeboard on the dam of more than 3 feet. By regulating the outflow during September at 2,000 second-feet, which could be taken care of by the outlet channel if necessary, the storage could be reduced to 7.8 billion feet by October 1, and with a flow of 1,000 second-feet from then on the reservoir would be emptied by early in January. If the heavy July run-off were to occur in June, with that of June transferred to July, the maximum storage would be 10.6 billion cubic feet. If in addition to closing the reservoir for 15 days at one time it should become necessary, on account of some great storm, to close it at another time for a short period, say 4 days, an increase in the rate of outflow to 1,400 second-feet would in 10 days bring the storage back to normal. In all cases the reservoir would be empty before the heavy spring run-off of the following year begins. These conditions are extreme and in all probability never will occur; but should such a combination of run-off come, it can be controlled without damage to the reservoir and with less damage from flooding in the lower valley than would result from the unhampered flow of such run-off.

Should even worse conditions prevail than have here been considered, the reservoir would still be safe from destruction. The spillway and culvert together would be capable of discharging more than 4,000 second-feet when the water reaches elevation 985.0 in the reservoir. Before the water could rise high enough to overtop the reservoir the discharge through sluiceway and spillway would be more than doubled. To raise the reservoir to a height that would involve this rate of discharge would require a rate of run-off very much higher than has ever been recorded in the Red River watershed

for an area as large as that draining to Lake Traverse. A discharge from the reservoir of 4,000 second-feet would flood the lands below the dam during the time that rate was maintained, and for a short time afterwards. It appears, however, that ample capacity with a safety factor for the most extreme conditions that will occur will be provided by the proposed works, and that the necessity for discharge at the rate of 4,000 second-feet would occur only at long intervals, if ever. The factor of safety in the case of the reservoir is somewhat higher than would be considered necessary in designing channels for the uncontrolled disposal of run-off. This is considered advisable in view of the cost of the reservoir, and the extent of damage to the controlling works which would follow failure of the dam, as well as the disastrous results in the valley below.

THE OUTLET CHANNEL.

The location and courses of the proposed outlet channel are shown in figure 3, sheets 2, 3, and 4. Typical cross sections are shown in figure 4. As planned, the channel would follow the general course of the Bois de Sioux River with such cut-offs as are considered advantageous. It is possible to obtain a uniform slope of 0.0001 (about one-half foot per mile) for the entire length of 22½ miles. For the first 13 miles the proposed channel has a bottom width of 40 feet, widening out to 52 feet just above the entrance of lateral 1 of the secondary system (see fig. 3, sheets 2 and 3) and continuing thus for 4½ miles to the mouth of the Rabbit River where the bottom width again increases and continues at 80 feet to the end of the excavated channel, about 5½ miles south of Wahpeton. Side slopes of 1.1 are planned throughout. To obtain the necessary capacity in the Bois de Sioux channel between the end of the excavated channel and Wahpeton, it would be necessary to clear out the brush, trees, and debris, but no excavation is contemplated here. The sluiceway in the dam would discharge directly into the upper end of the outlet channel, and the spillway overflow would reach it just below through a short channel (see fig. 3, sheet 2).

The normal capacity of the upper 13 miles of the channel is 1,000 second-feet, increasing to 1,300 second-feet and 2,000 second-feet at the outlets of lateral 1 and Rabbit River, respectively, to provide for the additional flow entering at these points. A 10-foot depth of flow is sufficient to give these capacities, although a somewhat greater depth is available at all points below the outlet of lateral 1. To provide for extreme conditions it is planned to make the spoil banks on both sides continuous as far down as the outlet of lateral 1. This will permit a flow of 2,000 second-feet, which is 1,000 second-feet in excess of the normal capacity, without overflowing the adjoining land. The increased flow can be taken care of below this

point by the greater width and excess of depth available as noted above. The continuous spoil banks would necessitate the use of flood gates for the small drains entering this section of the main channel, and the construction of spoil-bank levees along the lower parts of the larger ditches that enter the outlet channel. Such an arrangement would make possible the drainage of the low, wet areas along the Bois de Sioux, and only under the most extreme conditions of flow, which seldom occur, would there be any danger of flooding the lands adjacent to the outlet channel.

THE SECONDARY DITCH SYSTEM.

The secondary ditch system is designed pirmarily to provide outlet for the local drainage which will be necessary in the development of the wet lands along the Bois de Sioux River. The ditches are placed also with the view of relieving the upper part of the main channel from the run-off from the adjacent land, leaving its entire capacity free for the removal of the discharge from the reservoir. The proposed locations of the seven laterals are shown on figure 3, sheets 2, 3, and 4. All would have final outlet into the main channel, with the exception of No. 7, which would discharge the water from Big Slough into the reservoir above the dam, thus permitting it to be controlled within the reservoir. These lateral drains are designed with capacities great enough to carry any probable run-off from their drainage areas and, because of construction limitations, are in most cases oversized.

BRIDGES.

On account of the enlarged channel along the Bois de Sioux, it will be necessary to replace most of the present bridges with larger ones. Several of the steel spans can be used at their present locations by readjusting their elevations and constructing approaches, and some of the present pile trestles can be utilized as approaches for new steel spans at the same locations. As the design of highway bridges is in most States controlled by the State highway department, no consideration has been given to the design of the bridges necessary, but it is assumed that steel bridges with concrete abutments will be used. It is estimated that six spans 60 feet to 80 feet in length, and 14 spans 20 feet to 28 feet long, will be necessary.

LOCAL DRAINAGE.

To gain full benefit from the proposed improvements, it will be necessary to supplement them by local drains in all parts of the affected areas. The secondary ditch system as planned herein will, to a certain extent, drain the land in the immediate vicinity of the ditches, but the main object of these ditches is to provide outlet for

thorough drainage of small areas. Although a large amount of local drainage is necessary in the watershed, plans for it are not discussed here. This work should be taken up under State drainage laws.

RESULTS OF IMPROVEMENTS.

Lake Traverse and the Bois de Sioux River constitute the outlet for 1,200,000 acres or 1,875 square miles of land, of which 1,345 square miles are in Minnesota, 170 square miles in North Dakota, and 360 square miles in South Dakota, as indicated in Table 1. Run-off from the higher parts, 1,087,630 acres, of this watershed now causes considerable flooding over an area of 112,370 acres of lower-lying lands divided among the three States as follows: Minnesota, 31,140 acres; North Dakota, 75,160 acres; South Dakota, 6,070 acres. This lower land is all directly tributary to Lake Traverse and the Bois de Sioux River below the location that has been suggested for the detention reservoir and dam.

The proposed improvements are designed to control the run-off from the upper watershed of 1,335 square miles above the proposed dam, (1) by storing in the reservoir all the run-off from this watershed during March and April; (2) by storing during other periods after May 1 the flow into the reservoir in excess of the 1,000 second-feet which would be discharged through the control outlet; (3) by storing all the run-off that occurs during any period of 15 days during the summer when the run-off from territory below the dam fills the channels farther down. The channel capacities and provision for control of run-off are so planned that when operating in conjunction with properly designed and constructed local drainage, the flow of water over the entire Lake Traverse-Bois de Sioux watershed can be so regulated that no serious damage will result from flooding or lack of drainage. As a result of the construction of the proposed improvements 112,370 acres will be protected from overflow and given good outlet drainage. The Lake Traverse-Bois de Sioux project is complete within itself. While it may, if desired, be included as a part of the larger Red River project, it can be prosecuted entirely independently of any other improvements.

COST ESTIMATE.

A statement of the necessary construction work together with the estimated cost of the various items follows:

Browns Valley levee and railroad embankment	$39,970
Dam, earth embankment	107,950
Spillway	66,960
Control sluiceway	67,960
Approach to outlet	25,700
Main ditch	394,770

Secondary ditch system	$198,900
Bridges	89,260
Flowage rights	284,760
Contingent expense (about 10 per cent)	123,770
Total	1,400,000

This estimated cost, if raised by special benefit assessment placed on the 112,370 acres of land which would be affected directly by the improvements, would approximate $12.50 per acre. The assessment could of course be made less than that amount per acre by placing a part of the expense on the 1,087,630 acres of land which comprise the upper portion of the watershed. Some benefits would also accrue to the lands north of Wahpeton. It is impossible to estimate closely the probable cost to the various interests until the laws under which the improvements will be constructed are known. The cost of reclamation is, however, very reasonable when the value of the land as it now is and as it will be when drained is taken into consideration.

RED LAKE—RED LAKE RIVER PROJECT.

The plans for improvements in Red Lake and Red Lake River as recommended in the report of the Corps of Engineers, United States Army (see House Doc. No. 61, 66th Cong., 1st sess.), contemplate the construction of a dam and sluices at the outlet of Red Lake for the control of lake stages and outflow, the building of rock jetties for the protection of the outflow channel, and the enlargement and straightening of the upper 45 miles of the Red Lake River channel. The construction of a lock for navigation is also considered but not recommended as necessary at this time. Certain features of the project are here described which are closely related to the larger Red River project described later.

RED LAKE.

Red Lake has an area of 441 square miles. The adjacent land on the north, east, and west is low and flat with small streams and drainage ditches entering the lake. The land to the south is high and rolling and of a sandy character. During periods of high water the lowlands are overflowed and the drainage systems rendered inoperative. Commercial navigation is carried on to a limited extent in the lake which is of ample depth for the purpose. The approximate elevation of extreme high water is 1,177 and of extreme low water 1,173, giving a range of 4 feet.

It is proposed to limit the lake to a range of 3 feet by a control dam at the outlet, providing for minimum and maximum surface elevations of 1,171 and 1,174, respectively, for calm-water conditions, with an allowance for wind tide of 1 foot, bringing the extreme stage up to 1,175. The range of 3 feet will provide a storage capacity

of 36,000,000,000 cubic feet, which will hold the estimated maximum annual flow of 25,000,000,000 cubic feet with a margin of 44 per cent.

RED LAKE RIVER.

The Red Lake River has its source in Red Lake and has a length of 193 miles. It flows in a northwestery direction for 71 miles to Thief River Falls, thence in a southwesterly direction for about 61 miles, and thence in a northwesterly direction for about 61 miles to its junction with the Red River of the North at East Grand Forks, Minn.

For about the first 37 miles at the upper end there is no definite valley, the stream following a tortuous course through the flat, swampy country with its bed about 5 feet below the general land level. Owing to the slight fall the channel has been obstructed and filled in until it is inadequate to carry even the normal high-water discharges without overflowing the adjacent land. The valley takes form at High Landing; it is about one-eighth mile wide at Thief River Falls and the width increases to three-fourths of a mile at the mouth. Between Thief River Falls and Crookston the river descends in a series of short rapids. Below Crookston the fall decreases, giving depth and velocities of flow which permit navigation by small launches between Fisher and East Grand Forks. Below High Landing the banks are of sufficient height to prevent overflow under high-water conditions except on the lower portion just below Fisher (fig. 3, sheet 13), where at extreme high stages the river breaks over and a part of the flow discharges through the Grand Marais (fig. 3, sheet 14). There are but two tributary streams of importance, the Thief River entering from the north at Thief River Falls, and the Clearwater River entering from the east at Red Lake Falls.

CONTROL OF RED LAKE.

The dam proposed for the control of the lake stage is of the ordinary type of reservoir dam adopted in that district, and consists of "a reinforced concrete floor resting on pile foundation, which in turn supports alternate piers and stop-log sluices." To prevent the refilling of the excavated outlet by littoral drift, it is proposed to construct jetties of loose bowlders extending about 1,600 feet out into the lake to the end of the excavated channel. The log sluice provided in the dam may be used for the passage of small launches between the river and lake. Tentative location for a regular lock was selected, should navigation ever warrant its construction.

IMPROVEMENT OF RED LAKE RIVER.

As the extent of navigation does not warrant the expensive operations necessary to render navigable the stretch of river from Thief

River Falls to Crookston, and as damage from overflow and flooding occurs only above High Landing, channel improvement is recommenended only for the upper part of the river. It is proposed to deepen and widen the first 45 miles of the channel, straightening it by cut-offs at excessive bends, and thus reducing the actual length of the dredged channel to 40 miles. With a bottom width of 60 feet, side slopes of 1½ to 1, an 8-foot depth of flow, and a uniform slope of 0.7 foot per mile, the capacity is computed to be 1,037 cubic feet per second. This size and capacity is considered necessary to carry, with a minimum bank clearance of 2 feet, the maximum flow of 800 second-feet which may be expected under such conditions as occurred in the wet years of 1904 and 1905.

RESULTS.

The most extensive benefits to be gained through this project will be in the improved flood and drainage conditions in the upper river, the lake, and the surrounding country. Next to this in importance is the advantage to water-power interests resulting from the controlled flow of Red Lake water. It is claimed that the project will be of benefit also to municipal water supply systems, and lastly that it will be of value to navigation in the lake and the upper reaches of the river.

DRAINAGE AND FLOOD PREVENTION.

High stages in the lake and upper river cause great loss in the surrounding country by submerging considerable areas and backing up into the drainage systems. The lowering of the lake surface and improvement in the river channel will prevent flooding, eliminate the backwater which now obstructs flow in the present ditch systems, and make possible adequate outlet facilities for further drainage operations. Hundreds of thousands of acres of land, it is stated, will be benefited, some by reclamation from a state of permanent nonproductiveness, and some by transforming land—the farming of which is at best a hazard—into land upon which profitable returns are practically assured. According to documents No. 27, Sixty-first Congress, first session, and No. 971, Sixty-third Congress, second session, there are now or will be a total of 485,300 acres benefited by drainage systems tributary to Red Lake and Red Lake River above Kratka, Minn. Of this, 236,800 acres lie within the Red Lake Indian Reservation. The Army engineers' report assumes that the 485,000 acres may reasonably be assessed $1 per acre for benefit to be derived from the project.

WATER POWER.

There are now in operation on Red Lake River four water-power plants having a total head of about 50 feet. The Army engineers

estimate that the control works at the outlet of Red Lake would cause a minimum increase in flow of 500 cubic feet per second, which would make possible a total increase during low-water periods of about 2,275 horsepower for the four plants now in operation. At undeveloped power sites having a total head of 150 feet the increase would amount to about 6,825 horsepower.

COST ESTIMATE.

The estimated cost of the proposed improvement as given in House document 61 is as follows:

Channel excavation in Indian Reservation	$266,457.00
Channel excavation in Pennington County	300,153.00
Jetties	108,300.00
Dam and auxiliaries	52,709.20
Administration	12,000.00
Contingencies	39,380.80
Total	779,000.00

APPORTIONMENT OF COSTS AND BENEFITS.

Following is an apportionment of the cost which is recommended by the report as equitably based upon the proportionate benefits received by the various interests:

Interests.	Costs.		Benefits.
	First cost.	Annual maintenance and operation.	
			Per cent.
Water powers	$240,000.00	$3,700.00	30.8
Indian lands	236,800.00	3,650.00	30.4
Lands outside Indian reservation	248,500.00	3,850.00	32.0
Municipal water supply	39,000.00	600.00	5.0
Federal Government for navigation	15,000.00	200.00	1.8
Total	779,300.00	12,000.00	100.0

ADMINISTRATION.

It is recommended in the report that the work of construction and operation be financed and accomplished through a drainage district organized under the laws of Minnesota, in cooperation with the Indian Bureau and under the supervision of the War Department, the Federal Government apportionment for navigation to be used to defray the expense of this supervision. The title to the works would be held by the drainage district, and all improvements made by the district would be in accordance with plans approved by the Chief of Engineers and the Secretary of War.

Preliminary proceedings are under way in several counties in Minnesota to organize a special improvement district to raise funds among the property owners for carrying on the work. The cooperation necessary between the Federal, State, and local authorities is not yet fully arranged.

The Red Lake-Red Lake River project is complete within itself and should be developed as a separate undertaking rather than as a part of the larger interstate Red River project. To attempt to combine the two projects would in all probability delay development in one or both without adding anything of value to either.

THE EFFECT ON RED RIVER OF THE NORTH.

The proposed increase in minimum flow in the Red Lake River would increase to some extent the low-water stages of the Red River below the junction of the two streams and the control of Red Lake would decrease the high stages at Grand Forks by about 1 foot or possibly 1½ feet. The effect in lowering high stages of the Red River would be slight because the drainage area tributary to Red Lake is small as compared with that of the Red River above Grand Forks and because the relative effect of storage on high river stages decreases as the distance downstream from the reservoir increases. On account of the general distribution and more rapid concentration of heavy run-off in the spring, the effect of the control of Red Lake in lowering high stages of the Red River would be more consistently noticeable at this season than during storm periods in the summer months.

RED RIVER PROJECT.

The problem presented by the Red River, considered alone, is essentially one of flood control. As an outlet for the drainage of the watershed it is capable, under ordinary conditions, of removing promptly the discharge of its various tributaries. It is only when excessive run-off occurs over all or a considerable part of the watershed that flood stages occur in the Red River. A relatively small reduction of the high stages would be sufficient to prevent overflow and the resulting damage. As there is no practicable method of entirely preventing the water from reaching the Red River in flood volumes, it is necessary that some plan be developed for controlling the flow within the channel.

There are four general methods of flood control or regulation which include practically all the devices employed for this purpose. These are the use of reservoirs, the construction of levees, stream diversion, and channel improvement. Often a combination of two or more of these methods may be necessary. In each of the methods there are a variety of plans, differing in details of design and construction by which the results may be accomplished.

RESERVOIRS.

A study of the map of the valley and the profile of the river makes it apparent that the employment of reservoirs is not feasible along any part of Red River Channel and that this method of improvement may at once be eliminated. The flat, almost level topography extending from 10 to 30 miles back from the channel on both sides along its entire length offers no opportunity for the creation of a storage or detention basin at any point. To secure sufficient storage to affect flood stages appreciably it would be necessary during wet periods to inundate great areas of the most fertile land in the valley as well as farm homes and urban districts. This fact alone, without consideration of the practicability and expense of dams and other features necessary, precludes the pursuance of this plan in connection with the Red River proper.

On some streams it is possible to control floods by the use of reservoirs on tributary streams. The possibility of so controlling the floods on the Red River of the North was investigated. It was found possible completely to control the run-off from the Lake Traverse watershed of 1,335 square miles and from the Red Lake watershed of 1,950 square miles. The Otter Tail River above Fergus Falls, Minn., is now quite closely controlled by storage in natural lakes which act as reservoirs, and as the demand for power increases the run-off from this stream will no doubt be more closely controlled than it now is by the power companies.

The possibility of constructing storage reservoirs on other tributaries was investigated. It would no doubt be possible to construct reservoirs on some of the streams and completely control the floods on the watershed above the reservoirs, but the benefit from such control at this time was not found to be sufficient to warrant the expense. On the Sheyenne River, for instance, there are several locations where it appeared that dams might be constructed that would impound the run-off from the watershed above. Because of the light precipitation on the Sheyenne watershed the amount of run-off is seldom large when compared with that of the Red, and the effect on flood stages in the Red from cutting off the flood discharge from the Sheyenne would apparently be relatively small. The data in regard to run-off from the Sheyenne are meager and more are necessary to determine with some certainty the probable run-off. On other streams which have relatively high run-off from small watersheds, such as the Buffalo River, Wild Rice River, Snake River, and Two Rivers in Minnesota, no sites suitable for reservoirs which would impound a large quantity of water at a small cost were found. On the tributaries of the Red, coming in from the North Dakota side, somewhat similar conditions exist and in addition the rainfall is considerably

lighter. As the valley develops and more complete protection from floods becomes necessary, the construction of reservoirs on some of the tributaries may be desirable.

LEVEES.

The physical features of the Red River channel and valley are fairly well suited to the levee method of flood protection, and good results could be obtained by the proper location and construction of levees. However, there are several reasons for concluding that the adoption of this plan is not at present advisable, except possibly in certain reaches of the river.

To secure complete protection under all conditions, it would be necessary to construct levees from 5 feet to 20 feet in height along both sides of the greater part of the channel. In addition, it would be necessary to levee most of the tributary streams for considerable distances above their outlets. The enormous yardage of earthwork involved in such operations and the difficulty and expense of obtaining right of way, especially through the cities and towns, would run the cost high above that of other methods only slightly less effective.

It has been shown that, although floods may occur at any point along the Red River during the spring months, and although above the Sheyenne River the Red River may during the summer reach stages that are damaging to property within the outer high banks, it is altogether unlikely that any trouble from high-river stages will occur below the mouth of the Sheyenne except during March, April, and the early part of May. It is shown in the following paragraphs that by means of stream diversion and channel improvement the damage from summer flow above the mouth of the Sheyenne can be eliminated, and that the spring floods along the entire length of the river, except in the case of ice gorges, can be so reduced that no serious inundation of the adjacent land will occur. The overflows do not attain damaging velocities, and in spring they occur at a time when the only resulting damage to crops is a delay in the spring seeding. Moreover, with the increase in rates of flow, due to possible improvements in the channel, the water cover would be shallow, of short duration, and of rare occurrence; therefore it seems evident that the great expense involved in a complete levee system would not be warranted at the present time.

As the country becomes more thickly settled, conditions may make the construction of levees advisable along certain stretches of the channel where complete elimination of flooding is not to be secured by other means. In this connection it would be well if all buildings and other construction of a permanent nature could be kept at least 300 feet back from stream banks in order to provide the space necessary for the waterway and embankments should such construction be

undertaken later. Furthermore, any local levee projects that may be taken up should be based upon some comprehensive plan in order that they may conform to possible future work of this nature.

DIVERSION FROM DAKOTA WILD RICE RIVER.

There are numerous places in the watershed where stream diversion in one form or another can be advantageously employed. Of such cases there is but one, that of the Dakota Wild Rice River, where this method can be employed for directly effecting an improvement of flow conditions in the channel of the Red River, in conjunction with other measures recommended in this report. Projects of this kind which directly affect the tributary streams only, are not here considered except in a general way and should be taken up under the laws of the States in which the streams are situated.

As the Red River lies in the center of a broad valley flanked on both sides by land of considerable height, it is impracticable to divert any of the flow in the main stream to other outlets. Neither is it possible to divert the flow of any of its tributaries away from the Red, except in the case of Lake Traverse watershed and this plan has been rejected for sufficient reasons as a result of previous investigations. Auxiliary channels parallel with the river would be more expensive than the levee construction necessary to gain equal results, and are quite impracticable. The one remaining applicable plan in the way of stream diversion, is that of relieving overloaded sections of the channel by changing the locations of the outlets of tributary streams. Such changes in location are possible in various stream outlets along the river, but under present conditions and in view of results obtainable by channel improvements of the Red, the only such change that will produce results warranting the expense involved is a change in the location of outlet for a part of the discharge of the Dakota Wild Rice River during flood periods.

Recommendations in this connection contemplate a wide, comparatively shallow floodway with a capacity of 2,250 second-feet, leaving the channel of the Wild Rice River a short distance above the town of Wild Rice, N. Dak. (see fig. 3, sheets 7 and 8), following a northwesterly direction to the channel of the Sheyenne River, and entering the latter at some favorable point. The exact location of the floodway should be determined by a more detailed study of the locality than has yet been made. The length of the floodway would be about 7 miles. In addition it would be necessary to improve the channel of the Sheyenne River from the point where the floodway enters to the mouth of the river (see fig. 3, sheets 8 and 9), providing for a flow considerably in excess of that which it now can carry. This can be accomplished by clearing the channel of obstruction, no excavation being necessary.

The floodway should leave the Wild Rice River with a bottom elevation somewhat higher than the river bed, and should be provided with a concrete inlet sluiceway with control gates by which flow can be entirely closed off. By cutting the sides to a gentle slope the whole channel can be used for meadow or pasture land except during the short periods of a few days or weeks at rare intervals when it will contain water. Such use of the channel will be advantageous not only agriculturally but also as a means of channel maintenance.

The portion of the Red River channel between the mouths of the Dakota Wild Rice and Sheyenne Rivers is rather restricted and badly obstructed in certain parts. Above Fargo it is somewhat larger than below but owing to greater obstruction has about the same capacity of flow. At present about 6,000 second-feet is the maximum flow that can be accommodated without overflow of improved property. By channel improvement this can be increased to 8,000 second-feet from the mouth of the Wild Rice to Fargo, and to 7,500 second-feet from Fargo to the mouth of the Sheyenne. Of course the smaller figure governs in the design for relief (see fig. 3, sheets 7 to 9, inclusive).

The rate of flow in this part of the river channel has exceeded 7,500 second-feet in the past, and without doubt will do so in the future unless steps are taken to control it. It is proposed here, by diverting part of the flow of the Dakota Wild Rice River and by controlling the run-off from the Lake Traverse watershed, to limit the flow in this portion of the channel of the Red River to a maximum of 7,500 second-feet, which can be carried by the improved channel without damage to contiguous property. As the outlet of the Wild Rice into Red River is but a short distance above Fargo, a large reduction in rate of discharge from Wild Rice will result in practically equal reduction in rate of flow in the Red River at Fargo and just below that point, where the channel capacity is restricted.

Considering first the summer flood flow (see Table 5), this is estimated at a maximum of 9,652 second-feet at Fargo; the probable maximum for the Wild Rice is 3,315 second-feet; for the Red above the mouth of the Wild Rice, 6,656 second-feet; and for the small streams between this point and Fargo, 520 second-feet. Assuming that when the flow at Fargo reaches the maximum of 9,652 second-feet the Wild Rice is contributing its maximum of 3,315 second-feet, the flow at Fargo can be reduced to less than the allowable 7,500 by diverting 2,250 second-feet from the Wild Rice through the floodway. On the other hand, if the Red River above the mouth of the Wild Rice, and the small streams between that point and Fargo, were all flowing at their maximum rates, the Wild Rice would be contributing only 2,476 second-feet, and by diverting 2,250 of this through the floodway the flow at Fargo would be kept within the

safe limit. In any case, when the flow at Fargo would amount to 9,652 second-feet without control, enough could be diverted through the floodway to reduce it below 7,500 second-feet without overtaxing the diversion channel. With the stage in the Red high enough to cause a flow of 7,500 second-feet at Fargo, the stage in the Wild Rice at the entrance to the floodway would be high enough, either from the flow of the Wild Rice itself or by backwater from the Red, to allow the withdrawal of the 2,250 second-feet at an elevation considerably above the bed of the Wild Rice.

The probable maximum spring flood flow at Fargo, amounting to 11,580 second-feet, is next considered. To produce such a flow would require that all the tributaries above this point should reach very nearly the maximum spring flow as noted in Table 5, and that each should crest at such particular time as would produce the maximum combined effect at Fargo. Although it is not believed that such a condition will ever exist in the case of summer floods, it is possible that it will occur in the spring. In this event the flow in the Wild Rice River would be 4,420 second-feet. By diverting 2,250 second-feet through the flood way, the flow of the Red at Fargo would be reduced by practically that amount. Assuming that the effect of the 2,670 second-feet flowing from the Lake Traverse watershed is reduced to 30 per cent before reaching Fargo, which under conditions of flood flow is considered liberal, it is seen that by closing the sluiceway at the Lake Traverse detention reservoir and completely shutting off this flow during the spring months the flow at Fargo from this source would be reduced by 1,870 second-feet. This, combined with a reduction of 2,250 second-feet caused by diversion of this amount from the Wild Rice River, would give a total decrease of flow at Fargo of 4,120 second-feet, which would bring the flow at this point well within 7,500 second-feet. With such control of the flow in operation and the recommended channel improvements described hereafter accomplished, the elevation of the flow line during such floods as that which occurred in 1897 would be lowered about 15 feet.

The surveys and investigation make it apparent that the overflow, during flood periods, of the land along the west side of the Red River where the Wild Rice and Sheyenne Rivers flow almost parallel with it, are not caused entirely by overflow from the Red. Both of these tributaries have channels of insufficient capacity to carry their flood flow and are partly responsible for the floods in this region. Consequently it will be necessary, in addition to providing a diversion channel for the Wild Rice, to improve the channels of the Wild Rice and Sheyenne Rivers above the points where the floodway joins them. While this probably can be more readily accomplished under

the laws of North Dakota, it should be done at the same time and in cooperation with the floodway project. The floodway would so relieve high-water flow in the Wild Rice below the intake that little or no work on the channel would be necessary below this point. The improvement of the Sheyenne channel below the outlet of the floodway would necessarily be included as a part of the Red River project.

CHANNEL IMPROVEMENT IN RED RIVER.

In considering possible methods for improving the channel of the Red River, two may at once be discarded as impracticable, taken either separately or in combination. These are cut-offs, and enlargement of the present channel. The number of cut-offs to be made, the great size of the excavated channel required, the depth of cutting necessary, and the disposal of the immense quantities of excavated material, require a scope of operations and present technical difficulties that would make the cost prohibitive.

The most economical plan in this connection, and a very effective one, is that of clearing the channel of the obstructions which greatly retard the flow and are in a large measure responsible for overflow during high-water periods. As previously noted, the channel throughout its length is more or less obstructed by trees, brush and undergrowth, artificial structures, refuse dumps, and débris of various kinds. Along certain reaches the channel is almost completely choked by trees with the exception of a narrow strip which serves as a low-water channel and is kept open by the continuous flow throughout the year. During high-water periods the entire channel is necessary to carry the flow and, as a result of the obstructed condition of the greater part of its cross-sectional area, the velocities are so low that the water passes through the channel at a slower rate than it is brought in by the tributaries. Such channel conditions also tend to cause serious clogging by floating ice when it is present.

It is recommended that from Wahpeton, N. Dak., to the Canadian boundary, a distance of 394 miles along the river (see fig. 3, sheets 4 to 20, inclusive), the channel be cleared of all trees, brush, deadfall, débris, and structures of all kinds except bridges, which seriously interfere with the free flow of water. If possible the entire high-water channel should be cleared. The channel, having once been cleared, should be maintained permanently in good condition. This can best be done by pasturing the channel, or using it for hay land. It is not believed advisable to include under this project the removal and rebuilding of all bridges which cause obstruction to flow, as most of these are of wood and will not be serviceable for more than a few years, after which they must be replaced or the crossings abandoned. In replacing present bridges and in constructing additional

ones, it should be required that all bridges shall span the whole channel and be placed high enough to clear the high-water flow.

The width of the channel to be cleared varies in different sections of the river and the amount can be determined only by a detailed survey. An approximation of average widths for three sections of the channel based on information secured during the survey gives the following: From Wahpeton to Fargo, 100 feet on each side of the present low-water or open channel; Fargo to Grand Forks, 150 feet on each side; Grand Forks to the Canadian boundary, 200 feet on each side (see fig. 4). With such a strip cleared on each bank the approximate average widths of open channel in the three sections mentioned above would be 300 feet, 430 feet, and 600 feet respectively. As a result, during high-water periods the volumes of water which would pass in a given time through this wide unobstructed channel would greatly exceed those under present conditions.

It is believed advisable to gain control, under this project, of a strip of land 200 feet wide outside the land actually to be cleared on both sides. This would provide ample space for operations and for limiting all encroachments. After clearing the channel, the part of it outside the low-water flow-line should, where possible, be seeded to grasses; this would not only provide pasturage or hay land, but also would aid in keeping down the cost of maintenance.

EFFECT OF CHANNEL CLEARING.

The value of channel clearing becomes more evident when the results are reduced to figures which show approximately the increase in carrying capacity of the channel that can thus be secured. The section between Wahpeton and the mouth of the North Dakota Wild Rice River at present will carry about 4,000 second-feet without overflow. By the proposed clearing this can be increased to 5,400 second-feet, which with the reduction in flood volumes obtainable through the Lake Traverse detention reservoir will be adequate to provide for the disposal of all spring and summer flow. From the mouth of the North Dakota Wild Rice to the mouth of the Sheyenne the capacity can be increased from 6,000 second-feet, its present value, to 7,500 second-feet. Between the mouths of the Sheyenne and the Red Lake Rivers, the capacity of the Red River channel is now 15,000 second-feet and this can be increased by about 3,500 second-feet which would be ample to prevent practically all overflow along that section of the stream. Below the mouth of the Red Lake River at Grand Forks the channel in its present condition will carry 25,000 second-feet; by clearing out obstructions a flow of 30,800 feet can be provided for throughout the remainder of its length in the United States. The increase in capacity securable amounts to from 20 per cent in the

larger part of the channel below Grand Forks to 35 per cent just below Wahpeton where the sectional area is much smaller. The construction of the improvement on Red Lake and Red Lake River will also have some effect in reducing flood stages below Grand Forks. On account of the considerable distance the water must travel to reach the river after leaving Red Lake, the effect of reducing the flow from that lake will be partly lost before Grand Forks is reached. These capacities indicate the rates of flow that can be accommodated throughout the length of each section without overflow at any point.

The increased capacity thus gained would not entirely eliminate flooding below the mouth of the Sheyenne River. The rates of flow provided for—18,500 second-feet below the mouth of Buffalo River and 30,800 second-feet below the mouth of Red Lake River—probably will be exceeded in the spring at intervals of from 10 to 25 years, during such floods as occurred in 1882 and 1897. It is possible that at still rarer intervals the summer flow may cause slight flooding, but it is highly improbable that this will occur, because overflow during the summer could only be caused by run-off about 40 per cent greater than has ever been recorded at that time of the year.

In all cases of flooding the river stages would, as a result of the improvements, be lowered by approximately 5 feet; this would reduce the flood damage to a point where further reduction would not be economical at present.

RESULTS OF IMPROVEMENTS ALONG THE RED RIVER.

The works recommended along the Red River between Wahpeton, N. Dak., and the Canadian line consist of: (1) A floodway connecting the Dakota Wild Rice and Sheyenne Rivers at some distance above their mouths; (2) the improvement of the Sheyenne channel below the floodway outlet; and (3) the clearing out of the Red River channel for a distance of 394 miles from Wahpeton to the Canadian boundary. The maintenance of these works when once constructed is essential to the success of the project.

The results of these improvements may be summed up as follows:

From Wahpeton to the mouth of the Dakota Wild Rice River the capacity of the Red River channel would be great enough to provide for any volume of water that will come, provided the recommended Lake Traverse storage reservoir is in operation; thus overflow along this section of the river would be eliminated.

The floodway channel from the Dakota Wild Rice to the Sheyenne River, functioning in conjunction with the Lake Traverse reservoir, would so control the flow in the restricted section of the Red River channel between the mouths of the Wild Rice and the Sheyenne that it would at no time exceed the rate of 7,500 second-feet, which can be carried without overflow through that section of the channel

when cleared of obstructions as recommended. Overflow of the Wild Rice and Sheyenne channels, below the points where the floodway joins them, would also be eliminated. Overflow of these channels above the floodway can be eliminated by proper channel improvements carried out under local authority in conjunction with the Red River project.

The capacity of the Red River channel below the mouth of the Sheyenne River would be increased to such an extent that only the greatest floods of rare occurrence would cause overflow, and in these the river-stages would be lowered 5 feet below the elevation they reach during similar floods under present conditions. Owing to this lowering of the river-stages and the greater rapidity with which the flood volumes would be disposed of, the extent, depth, and duration of inundation would be greatly reduced. The resulting damage would thus be reduced and the quick return to normal conditions would prevent serious delay to farming operations.

In short, if these improvements were properly effected and maintained all flooding along the Red River would be eliminated except for slight overflow below the mouth of the Sheyenne River on rare occasions under the most extreme conditions, and such overflow as may occur there would not cause serious damage.

In order that these results shall extend entirely to the Canadian boundary it will be necessary that the channel improvements be carried some 30 miles beyond the boundary. Otherwise, the sudden change from the open, unobstructed state of the channel to the choked condition which now obtains below the line, would cause the flooding of territory near the boundary both in the United States and in Canada. Some arrangement should be made with the Dominion of Canada whereby the channel improvement may be continued far enough to prevent such an occurrence.

ESTIMATES OF COST.

The estimated cost of the improvements along the Red River between Wahpeton, N. Dak., and the Canadian boundary follows:

Flood way (including concrete inlet)	$355,000
Improvement of Sheyenne River channel below the flood way	95,000
Improvement of Red River channel from Wahpeton to the Canadian boundary	3,300,000
Total in United States	3,750,000
Additional for work in Canada	250,000
Total	4,000,000

These estimates were prepared during 1920 and it is probable that by the time the organization is completed the costs of making the improvements will be somewhat less.

The Red River overflows damage 500,000 acres of land within the limits of this project. The improvements proposed therefore would afford the protection, as stated above, for an average cost of $8 per acre.

ORGANIZATION.

In the three States interested in these projects, as in most other States, action to secure drainage improvements to be paid for by special assessment must be initiated by a petition from owners of land that will be affected. The drainage laws of Minnesota, North Dakota, and South Dakota were passed for the same purposes, but they vary considerably in the organization effected for carrying on the work and in the details of procedure. The drainage and conservancy act of Minnesota was passed in 1919, and provides for large districts and confers upon a board of directors the necessary powers to construct such improvements as may be necessary to drain the land and to prevent overflow. In North Dakota and South Dakota action will probably have to be taken under the general drainage laws. These work satisfactorily where only one county in the State is interested, but the organization becomes rather cumbersome when a large number of counties are included. Under all of the laws it would apparently be necessary for the organizations in the different States to enter into an agreement among themselves in regard to the distribution of the cost of the work and the organization which would have charge of the construction. If satisfactory results are to be secured on projects of the magnitude of Lake Traverse-Bois de Sioux and the Red River of the North, it is essential that control of the project be definitely centralized both during the construction and afterwards for the purpose of maintenance.

One way in which the work could be handled would be for each State to organize the lands within its boundaries which will be benefited as a drainage district. The administrative officials of each district could then meet as one board which would have entire charge of the project as a whole. It would be the duty of this board to have the benefits apportioned to the lands in the district, to let contracts for constructing the improvements, and to arrange for necessary funds. After the benefits had been apportioned and the contracts let, proportionate parts of the cost could be certified to the district interested in each State and they could spread the cost over the benefited lands within their boundaries.

In the event that this method of carrying out the work proved difficult of operation or unsatisfactory it might be possible to have the legislatures of the several States interested enact legislation providing for the appointment of members of a joint commission which could be given the authority granted to commissioners of drainage

districts. An organization formed along the lines of that provided by the Ohio conservancy act should be able to carry on the work effectively and economically. If it is necessary to make provision for a special board or commission, care should be taken to see that the number of members is not too large.

Practically all streams, even the smallest, affect areas that extend beyond the control of any one interest; and as the effects upon any part of the lands through which they flow are not due to causes originating wholly within that part but to broadly distributed conditions these streams should, to an extent, be considered as public property. The conditions along a stream are the result of natural processes not confined to any locality, and the beneficial effects of streams, as well as the extent of damage due to their existence, are dependent upon the balance of affecting conditions throughout the watershed.

These conditions can be controlled to a great extent by artificial means and the natural processes so directed as to operate to the lasting benefit of mankind. As the development of any part of a watershed may affect other parts, it is most desirable that there should be some central authority over the whole, to regulate such developments so as to receive the most equitable distribution of benefits among all concerned.

Such authority is desirable not only in regulating the construction and maintenance of artificial development, but also in preventing deterioration of the natural waterways as they exist. All artificial works require inspection and repair from time to time to keep them in proper order, and all channels whether natural or artificial are subject to a variety of conditions which impair their usefulness.

Little attention to proper maintenance of watercourse channels, as such, has been given in the past and much damage has resulted from channel obstruction and ungoverned flow, where the only reason for such damage was the lack of authority and initiative to remedy the evil. The need of such authority is generally understood and admitted, but until some definite action is taken in the matter present conditions will continue. Legislative action regarding this should not only provide the necessary authority, but should also impose the responsibility for administering it, and fix penalties for failing to do so.

CONCLUSIONS.

Owing to peculiar topography, soil, and climatic conditions much of the land in the Red River drainage basin requires extensive artificial drainage although in many respects it is naturally well adapted for farming. Much has been accomplished in the way of reclamation of swamp lands and the improvement of run-off conditions, but further operations are necessary to provide adequate outlets and to relieve

overflow conditions, especially along the Red River. The danger of overflows makes the farming of large areas impossible or hazardous; also it interferes with urban activities and with transportation. These unfavorable conditions can be eliminated by carrying out the improvements as recommended.

The organization of these projects will require considerable time. Delays increase the probability that additional damage will be caused by floods. It is desirable therefore that action which will result in permanent organizations be started as early as may be possible. Coordinated effort on the part of the interested States and the Federal Government in the collection of data in regard to precipitation and run-off in the three States will result in securing much information of value for preparing detail plans for the work and for operation after the improvements are completed.

RECOMMENDED INTERSTATE PROJECTS.

Two interstate projects are recommended, each to be handled either by an executive board made up of district officials from each State or else a commission appointed for the purpose which would have full authority.

The tri-State Lake Traverse-Bois de Sioux project would include land in six counties, as follows: Roberts County, S. Dak.; Richland and Cass Counties, N. Dak.; and Traverse, Wilkins, and Clay Counties, Minn. The Red River project would include land in 12 counties, viz, Wilkin, Clay, Norman, Polk, Marshall, and Kittson Counties, Minn.; and Richland, Cass, Traill, Grand Forks, Walsh, and Pembina Counties, N. Dak. It is recommended that the two projects include all the territory along Lake Traverse, Bois de Sioux, and the Red River.

In controlling run-off and stream-flow various interests such as land drainage, flood prevention, water power, navigation, and others sometimes overlap and conflict. In the two projects proposed herein no serious conflict is foreseen. Should any question as to priority of interest develop it is believed that land drainage and flood prevention will be recognized as of much greater importance than any other interests here involved.

BENEFITS AND COSTS.

Damages from floods and lack of drainage on large areas can only be approximated. It is conceded generally that large losses from these causes have been sustained in the Red River Valley. According to conservative estimates the loss due to the 1897 flood alone was over $7,000,000. As the value and amount of property in the valley is constantly increasing the danger of much greater losses from floods and lack of drainage is increasing also. At present a flood equal

to or greater than that of 1897 would cause much more damage than was caused by that flood. By improving the river channel as proposed, flood heights could be reduced by 5 feet or more and additional outlet facilities needed in some localities would be provided.

Benefits which would accrue from improved drainage outlets such as are proposed in the Lake Traverse-Bois de Sioux project would add greatly to the value of the land affected.

It appears, therefore, that the two projects are well worthy of adoption. The benefits that would be secured during future periods when large run-off occurs, such as now causes floods, will be large enough to warrant a considerably greater expenditure than will be necessary to obtain relief from these conditions.

ACKNOWLEDGMENT.

The authors desire to acknowledge their indebtedness to the following, who furnished valuable data and suggestions in addition to those noted elsewhere in the report: Mr. E. V. Willard, commissioner of drainage and waters, Minnesota; Mr. W. A. Robinson, State engineer, North Dakota; Mr. Homer M. Derr, State engineer, South Dakota; Messrs. T. R. Atkinson and J. W. Bliss, formerly State engineers, North Dakota; Mr. E. F. Chandler, professor of civil engineering, University of North Dakota; Mr. R. H. Slocum, professor of civil engineering, North Dakota Agricultural College; Mr. E. J. Dugan, assistant engineer, United States District Engineer's Office; Mr. A. V. Taylor, engineer, Otter Tail Power Co.; Messrs. J. G. Sullivan and Douglas McLean, engineers, Manitoba Drainage Commission; Mr. W. P. Brereton, city engineer, Winnipeg, Manitoba; Mr. L. W. Burdick, city engineer, Wahpeton, N. Dak., and Breckenridge, Minn.; Mr. W. B. Stevenson, acting city engineer, Fargo, N. Dak.; Mr. C. G. Selvig, superintendent, Northwest Substation, Minnesota Agricultural Experiment Station; Mr. George A. Ralph, formerly State drainage engineer, Minnesota; Mr. T. A. Hoverstad, agricultural agent, Minneapolis, St. Paul & Sault Ste. Marie Railway; the engineering departments of the Chicago, Milwaukee & St. Paul Railway; the Northern Pacific Railway; the Great Northern Railway; and the Minneapolis, St. Paul & Sault Ste. Marie Railway; county officials in charge of drainage records in all counties in the Red River Valley in Minnesota, North Dakota, and South Dakota.

In addition to the persons mentioned, many citizens of the valley rendered valuable aid during the progress of the work.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 1018

Contribution from the Bureau of Plant Industry
WM. A. TAYLOR, Chief

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WATER-STRESS BEHAVIOR OF PIMA COTTON IN ARIZONA.

By C. J. King, *Assistant, Office of Biophysical Investigations.*

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SCOPE OF THE INVESTIGATIONS.

American Egyptian long-staple cotton, which was first grown commercially in 1912, is now one of the principal crops of Arizona and portions of California. In 1920 approximately 250,000 acres were planted to this crop in the States mentioned. The acreage planted to the Pima variety of American Egyptian cotton in the Salt River Valley far exceeded that of any other crop in 1920.

An investigation of the practicability of using soil-moisture determinations as an index of the water requirement for growing Pima cotton was begun in 1918 and continued through the year 1919, in the belief that definite information would be of value in determining the best methods of irrigation, which is a very important feature in the production of the crop. The plan in 1919 was to apply water so as to keep different amounts of moisture available at various depths of soil and to study the behavior of the plants in response to the different proportions of soil moisture, in order to learn the quantity of water that would give the best development of the crop. This bulletin relates to the data obtained in 1919, after the experience of the previous year had demonstrated that it was possible to control

fairly accurately the amount of moisture in the soil by applying measured quantities of water at times when it was indicated by soil-moisture determinations that the moisture content had been depleted to the minimum point desired.

Although the experiments were not carried to the point of demonstrating a satisfactory method that could be recommended for general practice, it is believed that some of the data are of sufficient importance to be made available for other experimenters and for the interested public. As a result of these and other experiments it is now believed that the behavior of the plants will serve as a practical guide in judging the need of irrigation, making unnecessary the determinations of the moisture content of the soil except in critical cases.

Certain phenomena were noted in regard to the water relations of the different sizes of plants produced under varied soil-moisture conditions, indicating a retardation of growth and fruiting activities during the late development of the large plants. Also there is included a discussion of the period of maturation for Pima bolls, data for the shedding of immature bolls, distribution and depth of penetration of the roots of Pima cotton, and other phases of the irrigation problem.

LOCATION AND PLAN OF THE EXPERIMENTS.

The investigations were conducted in a large commercial planting about 1 mile west of the Capitol Building, Phoenix, Ariz. The soil is a heavy clay loam in the first 18 inches, closely resembling adobe in properties. Beneath this is a layer of coarse sandy loam, which at a depth of 5 or 6 feet is interspersed with concretions of calcareous material.

Seed of the Pima variety of American Egyptian cotton was planted on April 5, 1919, on four 0.1-acre plats, which were separated from each other and from the rest of the field by substantial dikes. The plats were approximately 33¾ feet wide by 129 feet in length, so that 9 rows could be planted 3¾ feet apart.

When the plants were about 10 inches in height they were thinned by hand pulling to intervals of 12 inches. A string with markers attached was used to insure exactness of spacing.

For controlling the content of moisture in the different plats the "wilting coefficient," as defined by Briggs and Shantz (*9*),[1] was used as a basis for indicating the dates of irrigation. The term "wilting coefficient" of a soil is defined by Briggs and Shantz (*9*) as the moisture content of the soil (expressed as a percentage of the dry weight) at the time when the leaves of the plant growing in that

[1] The serial numbers (italic) in parentheses refer to "Literature cited," at the end of this bulletin.

soil first undergo a permanent reduction in their moisture content as the result of a deficiency in the soil-moisture supply. By permanent reduction is meant a condition from which the leaves can not recover in an approximately saturated atmosphere without the addition of water to the soil. The water in a soil in excess of its wilting coefficient is called the "growth water," or "available" water; that is, it is the portion available for the growth of the plants.

The plan of irrigation was as follows: Plat 1 was to be irrigated at such frequencies that complete exhaustion of the available moisture in the upper 2 feet of soil, as shown by moisture determinations, would never occur during the period of plant development. Plat 2 was to be irrigated shortly before the depletion of all available moisture in the upper 4 feet of soil, and plats 3 and 4 were to receive water when it was indicated that the content of available moisture in the upper 5 feet was near the point of exhaustion.[2] In irrigating, the water was to be measured by means of a Cipoletti weir and applied in such quantities that the content of "available" soil moisture in the upper 4 feet of soil of plat 1 would be increased to approximately 7 per cent, that of plat 2 to approximately 5½ per cent, and that of plats 3 and 4 to approximately 4 per cent. It had been determined by preliminary experiments that a flow of one-fifth of a second-foot for four hours would increase the moisture content of an acre of soil approximately 1 per cent to a depth of 4 feet. After cultivations were discontinued some difficulty was encountered in maintaining close checks between the quantities of water applied, as measured by the weir, and that shown by moisture determinations following the irrigation, it being difficult to secure deep penetration, but the quantities determined in the soil samples for the different plats were relatively the same.

To determine whether the supply of plant food might bear some relation to the water requirement, plat 4 was given an application of cotton-seed meal and 16 per cent acid phosphate in the drill at the rate of 500 pounds per acre by means of a 1-row cotton planter.

Under the plan of moisture control, irrigations were found to be necessary on the dates shown in Table I.

TABLE I.—*Irrigations of Pima cotton found to be necessary for moisture control.*

Plat.	First.	Second.	Third.	Fourth.	Fifth.
No. 1	June 10	June 26	July 28	Aug. 21	Sept. 2.
No. 2	do	July 28	Aug. 21	Sept. 2	
No. 3	June 26	Aug. 15	Sept. 2		
No. 4	do	do	do		

[2] The available soil moisture in a field of growing cotton is first exhausted in the superficial layers of soil and is gradually reduced in ever-increasing depths of soil until the roots are limited in their power of penetration or the action is retarded by the application of water to the surface layers.

Beginning on April 22, soil samples for moisture determinations were taken each week in foot sections to a depth of 6 feet.

Immediately after thinning, 20 normal plants were selected in each plat and designated as observation plants. To minimize the error which might result from soil variations, 5 plants were selected 29 feet apart in each alternate row, excluding the outside rows, thus locating the 20 plants on four alternate inside rows, so that each represented an area of approximately one two-hundredths of an acre.

Measurements of the growth of the main stem of these plants were recorded each week on the same day that moisture samples were taken. This was accomplished by measuring from an india-ink mark near the ground to the tip of the terminal bud. In planning the experiments it was decided that a detailed study of a few individual plants selected in the above-described manner and produced under different conditions of soil moisture and available food supply would be of greater service in providing a better knowledge of the water requirements of the crop than a cursory inspection of a large number of plants studied collectively.

Beginning with the appearance of the initial flower about June 30, the flowers on each of the selected record plants were marked with the date of opening, in order to determine the length of the development period of the boll and to obtain information in regard to shedding.

ADAPTATION AND LENGTH OF THE DEVELOPMENT PERIOD.

The Pima variety, which is the only kind of cotton now grown in the Salt River Valley, seems in many ways admirably adapted to the climate of that district. Thus far in the history of the industry there have been no very destructive insect pests or diseases to affect the yield on a large scale, and storm damages have been infrequent. Yields of a bale and more per acre have not been uncommon, yet the average yield for the whole producing area for several years has been less than one-half bale per acre. Some of the growers would attribute this low average to the comparatively long development period required by the Pima Egyptian crop. While other factors, such as the location of a part of the crop on poorly adapted soils and in the hands of inexperienced growers, undoubtedly are largely responsible for the low average yields, yet the length of season required is of no little importance in the greater part of the Salt River Valley, where comparatively early frosts have been responsible for serious damage to the late crop of bolls. This has been the case especially where heavy soils or delayed preparation made planting impossible before the middle of April. It has been estimated by some of the growers that the heavy frost of November 1, 1919, was responsible for destroying from 15 to 20 per cent of the bolls on about

half of the cotton acreage in the Salt River Valley. No estimate was made by the writer for the whole valley, but in several fields visited it appeared that from 30 to 40 per cent of the bolls had been destroyed. The variation in season from year to year will not permit any rigid rule to be fixed for a critical date of planting, and consequently mistakes are made in planting too early as well as planting too late. The prolonged period of frosts and low temperatures occurring in late March and early April, 1920, was responsible for very heavy loss to the cotton growers of the Salt River Valley on account of the poor stands which resulted.

The Pima cotton plant will continue to develop bolls during a long period when environmental conditions are favorable. The writer has observed flowers to be still appearing on plants which had commenced flowering 150 days previously. However, the normal period of flowering for the Pima variety in the Salt River Valley is from 90 to 110 days. Results by Ewing (*12*) in Mississippi and Lloyd (*19*) in Alabama show that the length of the flowering period in those States for Upland varieties is from 40 to 80 days. The flowering curves of Balls (*3*) show that in Egypt the flowering of Egyptian varieties continues through a period of 120 to 140 days, while flowering curves for Sea Island cotton in the West Indies as presented by Harland (*14*) show that the duration of the principal fruiting period there is from 140 to 150 days.

In Egypt Balls (*3*) places considerable importance on "the time of arrival" of the cotton crop; this is not so much because of frost damage as because of the injury resulting from "root asphyxiation," when the water table rises in late summer. After the flood season of the Nile, when the water table has been lowered, the flowering often revives and continues through October and into November. Harland (*14*) states that in the West Indies the time of arrival of the crop is not of practical importance. In Arizona the general tendency of the Pima variety is to continue flowering at a somewhat reduced rate throughout the month of September, but not infrequently many of the bolls set during this month are damaged or destroyed by early frosts.

The percentage of bolls set in September, 1919, which reached maturity on the heavy soil above described in which the seed was planted on April 5, was as follows: Plat 1, 51; plat 2, 40; plat 3, 39; plat 4, 41.

The period of maturation for bolls of Pima cotton, as derived from the data obtained by the writer during the season of 1919, is considerably longer than that given by any commercial variety reported to cotton literature. Ewing (*12*) gives the mean length of the boll-development period of small-boll Upland long-staple varieties in Mississippi as 51.5 days and for small-boll early varieties 48.5 days.

Balls (*3*) gives 48 days as the mean for standard Egyptian Mit Afifi at Cairo, and Harland (*14*) reports 51 days for the mean of Sea Island cotton in the West Indies.

The mean development period, as determined for 3,319 bolls of Pima cotton at Phoenix, Ariz., during the season of 1919, was 68 days. Results[3] obtained by Leding at Sacaton, Ariz., which indicated that the length of the period of development of the boll for the Pima variety during the season of 1918 averaged 67 days would seem to substantiate the above data as to the mean lengths of the development period. Mr. Leding's data also conforms to that of the writer in regard to the lengthening of the period as the season advances.

The lengthening of the period of development of the boll in the later months, as shown in Table II, is also in agreement with the results reported by Allard (*1*) and Ewing (*12*) in the Southern States, showing that the early bolls matured within a shorter period than the later bolls. While the climate of the Salt River Valley is reported to be similar in many respects to that of the Nile Valley in Egypt, it would appear from the reports of Balls (*3*) that no such lengthening of the boll period occurs there. Balls speaks, however, of the effects of environmental influence on the boll period and states that it is eight days longer in the Middle Delta than at Cairo. It is also apparent from the reports of Harland (*14*) that no such lengthening of the boll period occurs in the tropical climate of the West Indies.

From a study of the results shown in Table II, it would appear that there is no relation between soil-moisture conditions and the period of boll development. It also seems evident from the results shown in Table II that the heavy application of fertilizer containing 10 per cent of available phosphoric acid had little or no effect in hastening the maturity of the bolls produced on plat 4.

TABLE II.—*Monthly variation in the development period of the bolls of Pima cotton in 1919.*

Plat.	Average soil moisture during flower production (per cent).	Length of period (days) for flowers opening in—		
		July.	August.	September.
No. 1	5.0	55.8±0.14	69.5±0.30	80.4±1.76
No. 2	3.1	54.4± .18	68.3± .35	80.9±1.91
No. 3	2.5	53.2± .13	67.5± .30	85.4± .42
No. 4	2.8	53.2± .15	66.2± .30	81.1± .49
Mean temperature, °F		76.5	75.9	69.0

WATER-STRESS BEHAVIOR.

The irrigation on June 10 of plats 1 and 2 caused the plants in these plats to grow more rapidly than those in plats 3 and 4, which

[3] Unpublished. Kindly furnished to the writer for use in this bulletin.

did not receive their first irrigation until June 26. (Pl. I.) Throughout July and August the plants in plats 1 and 2 continued to grow more rapidly and exhibited a more luxuriant growth. This is shown in the diagrams in figure 1, which gives the growth in inches per plant per week and the average percentage of available moisture per week in the upper 4 feet of soil in each plat.

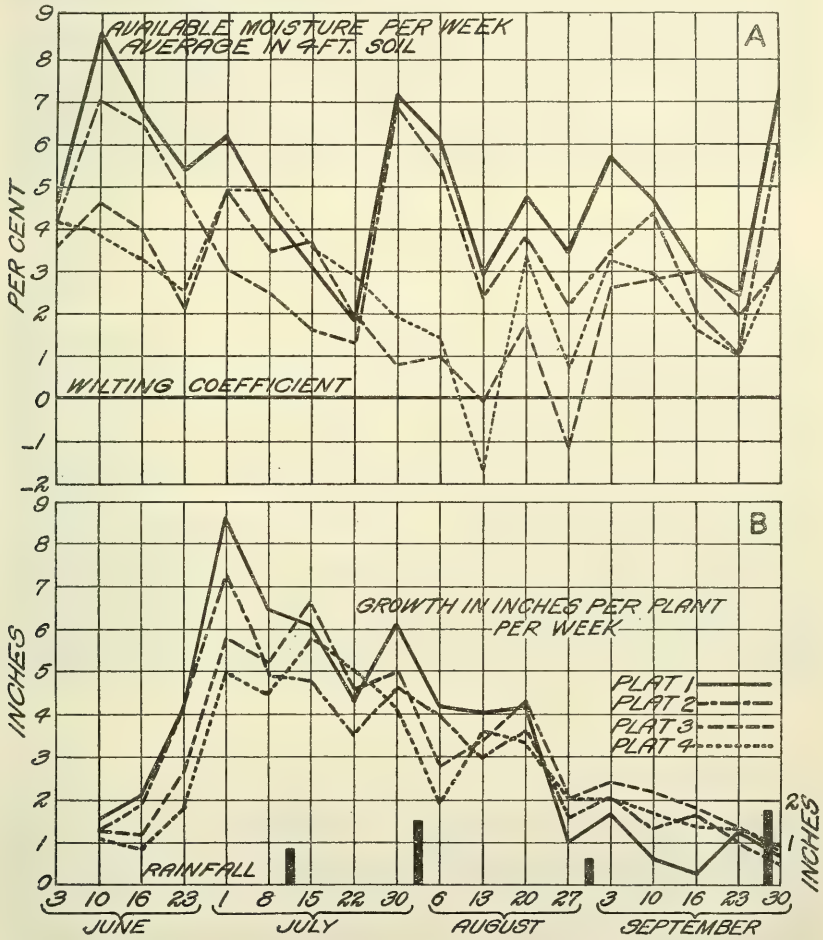

FIG. 1.—Average percentage of available moisture per week in the upper 4 feet of soil in four plats and the average increase in growth of the main stem of the plants per week.

During periods in the summer when very high temperatures were prevailing and when transpiration by the plant was at its highest, it was observed that the plants on plat 1 exhibited what might be termed a "water stress" in more pronounced degree than those on any of the other plats. This stress was made manifest by the wilted appearance of plants on plat 1, which occurred more frequently and

continued through a longer period during the day than on the other plats. Increasing the soil moisture in plat 1 was effective in preventing this wilting for only a short time. In six or seven days subsequent to an irrigation the plants would again show a loss of turgor of the leaves under the heat of the sun toward the middle of the day.

Balls (*3*), in considering the functions of the cotton root system, states that "since deficient water absorption is the real limiting factor in the sunshine effect, it follows that the size of the root system is the true limiting factor of water absorption and that the humidity of the soil may vary between wide limits without affecting it." In the effort to determine whether there was any difference in the root systems of plants on the four plats which might account in part for a deficiency in water absorption by the larger plants, excavations were made on March 1, 1920, and several plants were removed from the ground with all of the roots that could be traced in the upper 18 inches of soil. It was found that the roots had lived through the winter, and only a few of those uncovered showed any signs of decay. A count was made of all lateral roots attached to the 18 inches of taproot, a summary of which is given in Table III.

TABLE III.—*Count of lateral roots attached to top 18 inches of the taproot of Pima cotton in 1919.*

Plat.	Mean number of laterals.	Number of observations.
No. 1	34.6±1.56	13
No. 2	32.1±1.49	15
No. 3	24.4±1.08	17
No. 4	38.2±1.09	30

It is not a far-fetched supposition that the earlier irrigation received on June 10 by the plants on plats 1 and 2 would have encouraged the production of lateral roots near the surface of the ground and that the roots of plants not receiving early irrigations would have been forced to make their way into the deeper subsoil in order to obtain moisture, while the formation of laterals in the dry topsoil would have been somewhat suppressed. It appears from the results shown above that this did not occur. While a considerably greater number of laterals was found on plants from plats 1 and 2 than on those from plat 3, the greatest number of laterals was found on the plants removed from plat 4. It is not inconceivable that the liberal application of fertilizer supplied to plat 4 might have some bearing on the occurrence of this large number of surviving laterals in the topsoil, but until more detailed investigation has been com-

FIG. 1.—PLAT 1 ON AUGUST 10. IRRIGATED ON JUNE 10, JUNE 26, AND JULY 28.

FIG. 2.—PLAT 2 ON AUGUST 10. IRRIGATED ON JUNE 10 AND JULY 28.

FIG. 3.—PLAT 3 ON AUGUST 10. LIGHTLY IRRIGATED ON JUNE 26. NOTICE THE CONTRAST IN THE SIZE OF LEAVES ON PLATS 1 AND 3.

PLATS OF COTTON IRRIGATED ONCE, TWICE, AND THREE TIMES.

A COTTON ROOT MEASURING 10 FEET 8 INCHES WHEN IN ITS NATURAL POSITION IN THE SOIL.

THE ROOT SYSTEM OF MATURE COTTON PLANTS.

A FIELD OF COTTON IRRIGATED IN ALTERNATE DEEP FURROWS FOR THE PURPOSE OF PREVENTING EXCESSIVE PLANT GROWTH ON HEAVY RICH SOILS.

pleted along this line it is perhaps unwise to enter into its further discussion.

Although realizing the experimental difficulties to be encountered in studying the root systems of the plants in their entirety, the writer attempted to trace some of the taproots to their maximum depth.

Hunt (*15*, p. 311) cites Bulletin 7 of the South Carolina experiment station (1892) as reporting that in sandy soils well-developed taproots were traced to a depth of 2 to 3 feet without coming to their end. Balls (*3*) states that "the greatest depth to which an unbroken taproot has actually been followed is 2 meters and 20 centimeters" ($7\frac{1}{4}$ feet). Effort was made by the writer and his colleague, Mr. J. Z. Richardson, to trace taproots to their greatest depth on all of the plats. Departing from the usual custom of removing soil from around the roots by means of a trowel and a jet of water, small hand picks were used. Success in reaching the tip of a taproot was met with only on plat 3. From a trench excavated 12 feet in depth near the side of the plants, a taproot was removed from this plat which had attained a depth of 10 feet 8 inches from the surface of the ground. (Pl. II.) On the other plats several taproots were followed to a depth of 7 or 8 feet, only to lose them when their direction departed considerably from the vertical. The tip of one secondary root was found on plat 1 at a depth of 7 feet, but there was nothing to indicate that most of the roots did not extend to a depth as great as those on plat 3.

Contrary to expectations and to statements in the literature of the subject, it was found that a great number of the secondary roots grew vertically downward in the soil after having grown obliquely for some distance. (Pl. III.) From all appearances the primary roots had performed their normal functions but were assisted by these deep-seated auxiliaries, which at considerable depth could not be distinguished from the primary roots. Upon considering that the plants were spaced only 12 inches apart and that during a part of the summer the water requirement for single plants was more than 3 pints a day, this extensive development of a deep root system does not seem surprising.

Upon examination of the roots it was found that there was little difference in the root systems of the plants from the different plats, either in distribution or in the size of individual roots. Caliper measurements were made of the diameters of all the roots which were studied. The measurements were taken on the lateral roots by applying the calipers about 4 inches from their point of attachment to the taproot. It was found that the mean number of lateral roots over one-eighth of an inch in diameter was 2.8, 2.7, 3.0, and 2.6 per plant for plats 1, 2, 3, and 4, respectively.

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The taproots of the large plants were proportionately larger than those of the small plants to a depth of 10 or 12 inches below the surface of the ground, but at a greater depth than this they were not larger in diameter than those of smaller plants. Such data would seem to indicate that a limiting root system may have an important bearing on the water-stress behavior of the largest plants, it being a logical conclusion that the root system required for supplying the water demands of a large plant would be larger than that of a small plant.

In order to have additional data on this point, attention was next directed to the relative quantities of vegetative material produced on the different plats and to the demands made upon the moisture of the soil in supporting this material.

From the difference in the moisture content of the soil samples, which were taken at weekly intervals and also just before and two days following all irrigations, it was possible to compute the moisture lost from the soil during any week or month and for the entire period of development of the plants. The average quantity of water lost per acre each day (Table IV) was determined by dividing the weight of water lost from an acre during the entire month by the number of days in the month. The quantity of dry matter produced per unit area was determined by harvesting the plants when fully matured on an area of 900 square feet near the center of each plat. These samples, which included practically all of the dry matter produced above ground, were placed on canvas sheets and dried by the sun until they had reached a constant weight. Subsamples were then taken and dried at 110° F., and from these results the air-dried weights were corrected and taken to represent the average production of dry matter on the entire plat. The field water requirement was determined after the method of Briggs and Shantz (*10*), by dividing the total weight of the water lost from the soil during the whole period of growth by the total dry weight of the crop.

TABLE IV.—*Comparison of monthly water loss and dry-matter production by Pima cotton on plats 1 and 3 in 1919.*

Month, 1919.	Water lost per acre.				Dry matter produced per acre (pounds).		Field water requirement.	
	Inches.		Tons per day.					
	Plat 1.	Plat 3.	Plat 1.	Plat 3.	Plat 1.	Plat 3.	Plat 1.	Plat 3.
May	1.2	0.9	4.4	3.3	5,426	4,013	894.8	853.6
June	5.5	2.4	20.8	9.1				
July	5.6	4.5	20.5	16.5				
August	6.4	6.0	23.4	21.9				
September	2.7	1.3	10.2	4.9				

Table IV shows a striking contrast in the quantity of water used by the plants on plats 1 and 3 during May and June. The table also shows that during the month of June more than twice as much water was lost from plat 1 as from plat 3. The difference is all the more striking in view of the fact that the direct evaporation from the soil surface must have been less on plat 1 because of the shade afforded by the large plants (Pl. I). On July 8 the average height of plants in plat 1 was 7.5 inches greater than the average height of the plants in plat 3. Table IV further shows that, when calculated to an acre basis, plat 1 produced 1,413 pounds more of dry matter than plat 3. The water requirement (pounds of water expended per pound of dry matter produced) is shown to be about 5 per cent greater for plat 1 than for plat 3.

TABLE V.—*Comparison of the height of Pima cotton plants and the percentage of shedding on plats 1 to 4 in 1919.*

Plat.	Height, Sept. 1 (inches).	Total bolls shed prior to Oct. 1 (per cent).
No. 1	63	26.6
No. 2	55	21.5
No. 3	54	16.7
No. 4	50	17.8

WATER RELATIONS AND THE SHEDDING OF IMMATURE BOLLS.

From Table V it will be seen that the greatest percentage of shedding occurred on the largest plants growing in soil which constantly contained the greatest quantity of available moisture. Such an occurrence would seem to be at variance with that observed by many investigators who have studied the shedding of the Upland cotton plant.

Barre (*5*, p. 23–24) states that "lack of sufficient soil moisture is the principal factor in determining shedding." Ewing (*12*) concludes "that a deficient supply of soil moisture will result in excessive shedding." Balls (*4*) in reporting shedding studies with Egyptian cotton states that "shedding becomes abundant toward the end of the interval between irrigations and decreases directly after watering, but finally becomes excessive again when the water level is raised and the lower soil becomes saturated." Evidence, however, is not lacking that the water content of the plant itself may be an important factor in furnishing the stimulus for the shedding of squares and young bolls, and to the writer it appears significant that most of the investigators have proposed this factor as bearing an important relation to abscission. Harland (*14*) credits Nowell with the state-

ment "that shedding occurs when, from any cause whatever, the amount of water taken in by the roots falls short of that given out by the leaves." Ewing (*12*) reports from his observations that "it appears that the water content of the plant must have an important influence on shedding, and the water content is, of course, dependent on the amount of water absorbed by the roots and the amount transpired." Lloyd (*19*) concludes that "the water deficit is the cause of rises in temperature in the tissues, and this constitutes the stimulus which directly leads to abscission." Balls (*3*) has observed that "though the primary cause of shedding in Egypt is a deficient root absorption, it follows that an excessive transpiration rate must produce the same result, since the terms 'deficient' and 'excessive' are relative."

SHEDDING STUDIES UNDER ARIZONA CONDITIONS.

From the observations of the writer it appears that under Arizona conditions the severe water stress exhibited by plants possessing large areas of leaf surface and the shedding of squares and bolls are not always induced by a lack of "available" moisture in the soil. Such a conclusion may seem paradoxical in the light of general opinion, but to one who has studied the water relations of the cotton plant when grown under arid conditions it may not appear unreasonable. It is well known to plant physiologists that some plants are better provided than others with special structures for resisting too great a loss of water when growing under arid or desert conditions. The cotton plant seems to be one of the plants not so well equipped for reducing evaporation under arid conditions and frequently loses more water by transpiration than the roots can absorb from the soil. Recent work on the relations of plants to water supply, including contributions by Lloyd (*18*), Livingston (*17*, p. 216), Free (*13*, p. 114), Lyon and others (*20*), Coit and Hodgson (*11*), Balls (*3*), and others, had indicated that a feeding rootlet, by absorbing some of the soil solution with which it is in contact, creates a condition of instability which results in considerable film movement toward the drying-out zone. Undoubtedly it is the deficiency of this assumed property of capillarity in supplying the film moisture at a sufficient rate to replace the amount absorbed by the roots that accounts for the occurrence of water deficit in the tissues of the cotton plant, as shown so clearly in large plants with a great deal of transpiring surface. It is fortunately true that this deficit, occurring during the hours of hottest sunshine, is largely made up during the late afternoon and night, provided climatic conditions are not too stringent. When very dry hot weather occurs at a time when the soil conditions are unfavorable to the ready absorption of water by the roots, the shedding of immature fruits reaches its maximum.

It has been stated by both Lloyd (*19*) and Balls (*3*) that there is always observable a steady increase in the percentage or relative rate of shedding of squares and bolls as the season advances, the first squares formed having the lowest relative shedding rate and the highest rate occurring just before the plants begin to show a retardation of growth near the end of the season. Lloyd would explain this as probably due to the fact that the adjustment of the plant to its environment is not as good during the latter part of the fruiting season as earlier. Having observed the records of well water in which the water was gradually lowered during the summer and concluding therefrom that the moisture content was reduced in ever-

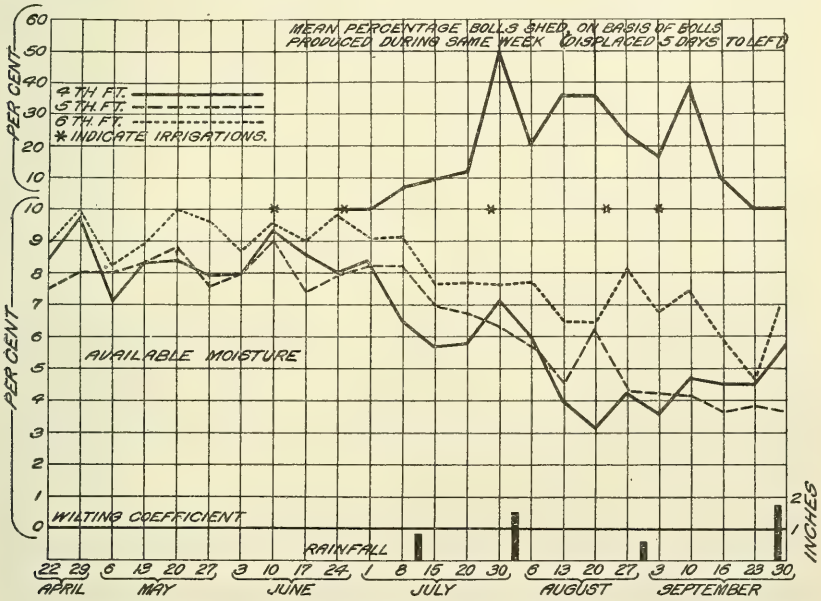

FIG. 2.—Moisture content of the deeper layers of soil and the mean percentage of bolls shed on the basis of the total bolls produced during the same week.

increasing depths of the soil as the season advanced, he reasons that this condition places a more severe tax on the plant and causes an increasing rate of shedding. Though Lloyd (*18*) presents no soil-moisture data to substantiate his hypothesis as to the relation of this factor to shedding, it appears from the results secured by the writer and confirmed by four years of observation of the water relations of the Egyptian cotton plant under arid conditions that Lloyd's opinion is well founded.

The amount of square shedding at Phoenix was so small at the commencement of the fruiting activities that no attempt was made to record the rate after the first three or four weeks. The curves representing boll shedding do not show the rate of shedding increasing with the advance of season to the marked degree exhibited in the curves presented by Lloyd. This, however, is not surprising when

it is remembered that Lloyd's observations were made under conditions where the soil-moisture content was increased only by rainfall, and this usually in such small quantities as to affect only the superficial layers of soil.

It will be observed from the curves of shedding (displaced) and of moisture content of the deeper layers of the soil as shown in figure 2 that there are indications of a correlation. Shedding began to increase coincident with the date (July 2) when the first important drop took place in the curve representing the moisture content of the fourth foot. Several years of experience in studying the subterranean conditions influencing the growth of the cotton plant have convinced the writer that the depth of the taproots and their rate of progress downward can be traced fairly accurately by means of frequent determinations of soil moisture. It seems evident from the curves that the roots had not reached the fourth-foot layer of soil in sufficient number to reduce the moisture content to any extent prior to July 2. Subsequent to this date, and especially following the reduction in moisture content of the fifth and sixth foot layers during this week, July 8 to 15, there was a rapid increase in the shedding rate. The increase was temporarily checked by the irrigation of July 28, which increased the moisture content of the fourth foot. Another node of high shedding rate followed soon after and continued until checked, evidently by the effect of the irrigation on August 21. The general trend of increasing shedding as the season advanced was finally checked in early September by the gradual cessation of plant growth.

That the depletion of moisture in the deeper soil is responsible for the increased shedding rate may be supported by other evidence noted in a different part of the Salt River Valley, where the water table has risen to within 5 or 6 feet of the surface, because of leaky canals, etc., and the soil is of a gravelly loam nature permitting the free movement of water. In this locality it was observed that cotton plants, although of large size, widely spaced, and having considerable transpiring surface, shed but few of their small bolls during the period when the shedding rate was highest in localities where the water table was not within reach of the cotton roots. In 1919 yields of a bale to the acre were not uncommon in this district, and one 7-acre field yielded at the rate of 1.7 bales of lint per acre. In other localities where the water table is still nearer the surface and where the soil has a greater capacity to retain moisture, it often happens that the plants grow to a height of 7 or 8 feet, and here the shedding is excessive as the season advances. This condition undoubtedly limits the roots which are functioning properly to a zone near the surface, and the strain imposed upon these roots by the great rate of transpiration apparently is a factor in the magnitude of the shedding rate.

THE PERIOD BETWEEN FLOWERING AND SHEDDING.

The interval between the opening of the flower and the completion of the abscission process is of some importance in identifying the stimulus which produces shedding. From Table VI it is apparent that there is little or no correlation between the length of this period and the moisture content of the soil at the time of flowering.

TABLE VI.—*Period of retention of shed bolls developing from flowers of Pima cotton blooming on successive weeks on four plats compared with the available moisture present in the soil during the season of 1919.*

Date.	Plat 1.	Plat 2.	Plat 3.	Plat 4.
July 16 ... days	9.0	8.2	7.7	8.1
22 ... do	10.8	10.6	6.0	10.7
30 ... do	7.8	13.8	12.5	8.5
Aug. 6 ... do	7.5	8.1	7.7	5.6
13 ... do	9.2	8.0	12.0	10.1
20 ... do	7.1	9.2	8.9	10.7
27 ... do	9.4	9.0	10.4	11.8
Sept. 3 ... do	16.1	16.5	15.1	12.0
10 ... do	18.3	13.8	8.8	10.4
16 ... do	10.6	9.5	6.1	10.0
23 ... do	16.2	10.2	11.3	21.2
Mean	11.1	10.6	8.8	10.8
Mean available moisture in top 4 feet of soil ... per cent	5.0	3.0	2.5	2.8

Ewing (*12*) states that "the period between flowering and shedding in general is longest when shedding first begins and shortest at the close of the season." Lloyd (*18*) shows that "there is little evidence that the mean of age frequencies of shed bolls was reduced during the season, but that there is definite evidence that the mean may recede or advance as a result of the additive or subtractive effects of stimuli, such as the additive effect of rain upon that of the soil moisture which resulted in a recession of the mean of three days." It appears from the results shown in Table VI that in Pima cotton there is a tendency for the period between flowering and abscission to increase as the season advances, under the conditions which obtained under this experiment, but the fluctuations were great even near the end of the season.

A study of the results in Table VI will show that there is only one weekly mean which exhibits clearly the effect of some stimulus operating generally on all the plats. This is the mean for the week ended August 6 when there was a recession of the mean on all the plats. It so happens that the only rain of any importance during the fruiting season fell on August 1 (fig. 2), so that there seems to be little doubt that rainfall was the responsible factor for the relatively large shedding of bolls during the week specified.

VARIATIONS OF PERIODICITY OF DEVELOPMENT.

The cotton plant, like many other plants, exhibits pronounced periodic variations in its developmental activity. Among these is the

period of hibernation, at the commencement of which the growth and fruiting activities gradually slow up and finally cease. Such behavior is considered entirely normal for the cotton plant, and it is commonly thought to bear a definite relation to the seasonal fall in temperature. A survey of the literature on the cause of such behavior reveals the presence of two widely diverse opinions, one of which views the cessation of activity as a direct response to changing external conditions and the other as the result of fixed, hereditary, internal causes. In the West Indies, where the tendency of the Sea Island cotton is toward perennial habits, the flowering curves as presented by Harland (*14*) show that a period of cessation in activity occurs about 90 days after the appearance of the first flower. After this, there is renewed activity and another distinct node is produced in the flowering curves. Balls (*3*) shows by growth and flowering curves that in Egypt there are remarkable differences between different strains of cotton grown under similar environmental conditions in respect to the time when growth and flowering cease. In discussing the phenomenon of cessation of activities he applies to it the term "senescence" and ascribes it to self-poisoning. He postulates that the influence is of a chemical nature, a thermotoxy local in and peculiar to the growing point.

From figures 1 and 3 it appears that in Arizona there may be variations in periodicity in the same strain, planted at the same time, grown in the same type of soil, and with all other conditions similar except soil-moisture content. This is noticeable during the later development of the plants when the transition from full activity into a condition of hibernation is taking place. It will be observed that until about August 20 the increase in growth per week was influenced by a proportionate amount of moisture present in the soil. After this date there was a more distinct slowing of the growth rate of plants on plats 1 and 2 than on the other two plats. This occurred despite the fact that the amount of soil moisture in plats 1 and 2 was greater than in the other two plats.

Balls (*3*) states that "when dealing with most pure strains, we find considerable uniformity in the date of the first flower. The stunted plants, if any, flower late, so that a close correlation here exists between the height of the young stem and the flowering date." However, in this connection he states that "all the plants of some strains in the author's possession (notably King Upland) come into flower almost simultaneously, even if some are stunted." In the writer's experiment, while there was a difference in the average height of the plants on the different plats at the time when flowering began, about June 30, there was a decided uniformity in the time the first flowers appeared. Though the average height of plants on

plat 4 at that time was only 17.5 inches, as compared with 25.7 inches as the average height of the plants on plat 1 (fig. 1, *B*, and Pl. I), it could hardly be stated that the former plants were stunted. At that time they were growing in a satisfactory manner, and apparently the supply of soil moisture was ample for their need.

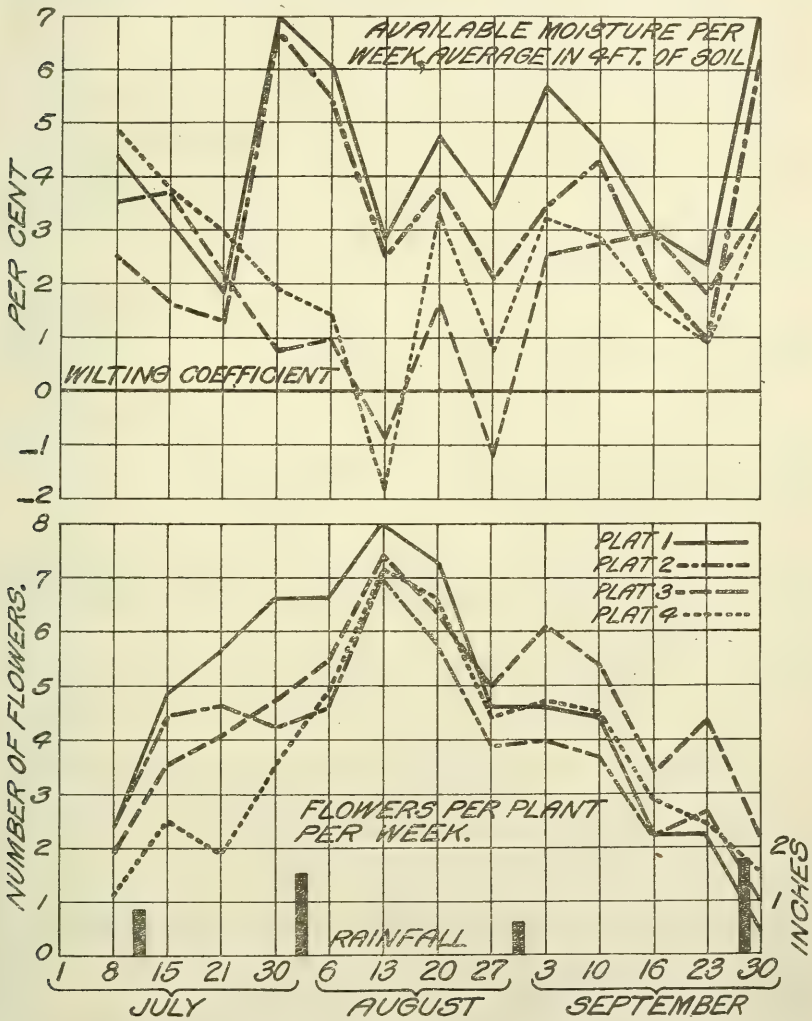

FIG. 3.—Average percentage of available moisture per week in 4 feet of soil and the weekly flowering curves of four plats.

Figure 3, *B* shows that the flowering rate of the plants in plat 1, which were growing at a more rapid rate than those of plat 3 (fig. 1, *B*) during July was greater than plat 3, but did not continue at the same relative rate later in the season. During the week August 20 to 27, the rate of flower production in plat 3 became equal to that

in plat 1. Following this week the plants in plats 1 and 2 were never so responsive to the influences which affect flowering as those in the other plats, and their curves dipped with considerable regularity after September 3 to a condition of almost complete cessation about September 30. The curves of plats 3 and 4 also dipped toward a hibernation period, but with greater fluctuation and a greater amount of flower production.

It will be observed that during this period of gradual cessation in flowering the different plats held about the same relative position in regard to the moisture content of the soil as at the beginning of the flowering season, plat 2 having usually the second highest and the moisture content of the other two plats having been almost constantly smaller than that of plats 1 and 2.

Data given in Table VII indicate that some economic importance may be attached to such an occurrence, especially in seasons when the first killing frost of the autumn does not arrive earlier than is commonly expected for the vicinity. A summary of the data obtained by the Weather Bureau shows that the average date of the first killing frost at Phoenix, Ariz., during the years 1895 to 1920 is December 3, or 33 days later than the date on which cotton was killed by the frost in 1919.

TABLE VII.—*Comparison of flowers produced and stem growth prior to August 15, plants producing vegetative branches, bolls produced on 20 plants during September, and September bolls destroyed by frost on four plats of Pima cotton in 1919.*

Plat.	Percentage of—				Bolls produced on 20 plants during September.
	Total flowers produced during first 45 days beginning with initial date of flowering.	Total stem growth produced prior to August 15.	Plants producing vegetative branches.[1]	September bolls destroyed by frost.	
No. 1	60.5±0.97	85.3	5	49±2.2	263
No. 2	58.6±1.01	80.4	40	60±2.3	215
No. 3	48.9±1.00	76.2	10	61±1.8	340
No. 4	46.8±1.08	76.9	10	59±2.1	264

[1] Most of the vegetative branches made only a rudimentary development. The flowers produced were so few as to have no material effect on the flowering curves or the final yield.

From the data in Table VII it is apparent that plats 1 and 2 would have produced considerably more cotton per plant despite the early frost had the later flowering continued at the same rate as that on plats 3 and 4. The relative production of both stem growth and bolls was considerably greater during the first 45 days of the flowering season on plats 1 and 2 than on plats 3 and 4. This may be attributed to the fact that plats 1 and 2 received their first irrigation 16 days earlier than plats 3 and 4.

It will be seen from Table VIII that the greatest number of flowers per plant was produced on plat 1, to which the greatest quantity of water had been added. However, on account of the greater amount of shedding on this plat there was a smaller number of bolls set by October 1 than on plat 3, which had received the least water. The "potential seed-cotton production" on October 1 of plants on plat 3 exceeded that of any other plat, but the "potential seed-cotton production" is not in accord with the actual production, as determined upon picking. This discrepancy can be accounted for by the records of frost damage to bolls, as shown in Table VII, the percentage destroyed having been greater in plat 3 than in plat 1. Bolls set late in September were not able to develop fully, and those which cracked open sufficiently to be picked were lighter in weight than those set earlier in the season.

TABLE VIII.—*Comparison of the flowers produced, the percentage of shedding, the bolls set, and the potential seed-cotton production in each of four plats of Pima cotton with the total yield of seed cotton per acre in 1919.*

Plat.	Mean number of flowers produced.	Mean percentage of shedding.	Mean number of bolls set by Oct. 1.	Mean potential seed cotton produced (grams).[a]	Yield of seed cotton per acre (pounds).
No. 1	58.2±1.79	26.5±0.38	43.1±1.71	106	1,602
No. 2	50.9±1.78	21.6± .34	40.0± .40	96	1,437
No. 3	57.0±2.16	16.7± .21	47.6±1.89	111	1,496
No. 4	48.2±1.30	17.8± .26	39.7± .36	95	[b] 1,397

[a] Mean "potential seed-cotton production" in the sense here used is the mean weight of seed cotton per boll as determined upon picking, multiplied by the mean number of bolls set per plant on Oct. 1.
[b] The presence of a "slick spot" of approximately 900 square feet in plat 4 was responsible in part for the low yield on that plat. This soil variation was not noted until its presence was indicated by the stunted condition of the plants.

Such data, Tables VII and VIII, seem to indicate that every precaution should be taken in growing cotton in areas where there is danger of damage from early frosts to stimulate the setting of fruit to the fullest extent during the months of July and August. The data show that the first irrigation on June 10 was not so early that it produced an excessive number of vegetative branches but served the purpose of stimulating the plants into early fruiting, which was especially important for that particular season. The 16 days lost by the plants in plats 3 and 4 in the early processes of fruit production was a handicap that they never overcame. While the cessation of growth and flowering immediately after the 1st of September might result in a reduction of the yield, such loss of time under Salt River Valley conditions would hardly result so seriously as an equal length of time lost at the beginning of the fruiting season.

The more pronounced slowing in late summer of the growth rate and flowering of cotton plants which had produced a heavy growth of vegetative material early in the season presents a very interesting physiological problem. The work of some recent investi-

gators (Klebs, *16*, and Appleman, *2*) in being able to maintain almost any plant in continuous growth throughout the entire year would seem to indicate that the importance of periodicity has been exaggerated.

It is difficult to interpret the behavior of Pima cotton as above described on the basis of an inherent periodicity, but it is not improbable that physiological reactions are involved. It is a common observation among growers that cotton plants once stunted by water shortage are much slower in response when water is finally applied than plants which have not been so severely checked. A case of this nature came under the writer's observation at the Sacaton station in 1920. Plants growing in a sandy soil showed visible distress from water shortage about two weeks before the first application of water on July 7. In response to this irrigation the plants grew only 9 inches in height during the ensuing three weeks and required two additional irrigations before complete recovery, while plants on adjoining plats, which had shown no water stress, grew 14 inches during the three weeks following the first irrigation and responded promptly to each subsequent irrigation by making additional growth. The fact that all external factors except soil moisture were closely alike for all the plants in these experiments and that there was a distinct difference in the promptness of response to this particular factor gives probability to the interpretation that the cause is internal, but is subject to remedy by control of the external factors.

When we come to consider the adoption of means for remedying this maladjustment of the plant to its water supply, the most practical line along which to work seems to be in modifying the conditions of the subterranean environment. The need for some such corrective measure seems especially imperative when dealing with heavy rich soils which cause a quick and vigorous response of the plants to irrigation water when applied by conventional methods.

An experiment was conducted in 1919 by the writer and his cooperator, Mr. Warren H. Parker, in adjacent plats to those above described, in the effort to effect more perfect control of the plant growth.[4] The plants were grown in pairs of rows, with a wide middle 5½ feet between pairs and a space of 3½ feet between rows. The water was run in deep furrows made in the wide middle (Pl. IV), while the narrow middles were left dry after the planting season. The effect of the water when applied under these conditions was not noted in the behavior of the plants until five or six days later, and

[4] A double-row method of planting and irrigating Egyptian cotton has been outlined in connection with the single-stalk method of suppressing the vegetative branches, and tested in recent seasons at the United States Experiment Farm at Bard, Calif., near Yuma, Ariz. (*6, 7, 8, 21*).

the moisture content of soil samples taken in juxtaposition to the plants 24 hours after the application of water showed no increase above the fourth-foot layer but marked increase in the fifth-foot layers. The plants grown under this method of irrigation in 1919 behaved in a very satisfactory manner and did not show the marked slowing up of the growth and flowering rates late in the season exhibited by the plants on plats 1 and 2. In 1920 this method of irrigation on heavy soil was adopted commercially by Mr. Parker and proved very satisfactory. The plants which were irrigated at approximately 10-day intervals during the principal fruiting season fruited very heavily, with little loss from shedding, and the total yield per acre was considerably greater than had been obtained on the same soil in several years previously. The encouraging results obtained in these tests with a double-row method of cotton culture and reports of frequent successes in tests with a somewhat similar method at the Bard station point to the need of further experiments along this line. There seem to be possibilities of solving several important problems of cotton culture under irrigation by perfecting some such method.

CONCLUSIONS.

This bulletin reports the results of an investigation of the behavior of Pima cotton when grown under different conditions of soil moisture and available plant food in the Salt River Valley of Arizona in 1919.

The normal growing season in the Salt River Valley, while usually ample for substantial yields, is none too long for the complete development of the Pima cotton plant, and precaution on the part of growers is necessary in selecting a proper date for planting and to keep the plants in full activity during the limited time available for boll production. The occurrence in some years of heavy frosts about November 1 has occasioned considerable damage to the late crop of bolls.

The mean period of maturation for over 3,000 bolls of Pima cotton was 68 days.

In Arizona early bolls mature within a much shorter period than later bolls. The mean difference in time required for maturation between bolls developed from flowers blooming in July and those blooming in September was 27 days.

Plants which had produced the greatest quantity of vegetative growth appeared to suffer most frequently from "water stress," remaining longer in a wilted condition between irrigations and showing an earlier recurrence of wilting after irrigation.

The fact that there was no appreciable difference in size or distribution between the roots of large plants and small plants seems to

indicate that a limiting root system may have an important bearing on the water-stress behavior of the largest plants.

Most of the taproots of both large and small plants extended to a depth greater than 7 feet, and the only one followed to its greatest depth measured 10 feet 8 inches in length. A considerable number of secondary roots extended to great depths and apparently shared the function of the taproot.

The greatest quantity of water was removed by the plants in plat 1, where the moisture content of the soil had been kept highest throughout the season, the amount removed during May and June being about twice as much as in plat 3. Plat 1 produced dry matter at the rate of 1,413 pounds per acre more than plat 3.

It appears that in Arizona the severe water stress frequently exhibited by plants possessing large areas of leaf surfaces and the shedding of squares and bolls from such plants are not always induced by a lack of "available" moisture throughout the soil mass, but may be due to a reduction of moisture in the portion of the soil immediately surrounding the roots more rapidly than it can be restored by capillarity.

There appears to be an important relation between the increase of the shedding rate (based on the number of bolls available for shedding) during the first two months of the flowering season and the gradual reduction of the moisture content in the lower soil layers.

The mean interval between the opening of the flower and the completion of the shedding process was approximately 10 days. The general tendency was for the period to increase as the season advanced, but fluctuation was great even near the end of the season.

A heavy rain materially shortened the interval between flowering and shedding.

In late summer a depression in the rate of growth and flowering was shown in the large plants much earlier than in the smaller plants. After this retardation began the large plants never again exhibited as prompt or vigorous a response to irrigation as the smaller plants.

Plants to which irrigation water was supplied soon after the first flower buds began to form, and frequently thereafter, produced a greater stem growth and a greater number of flowers during the first 45 days of flowering than plants to which water was not supplied until 16 days later.

Plants growing in soil which was supplied with water sparingly throughout the season produced a greater number of bolls late in the season than plants provided with larger supplies of soil moisture.

The highest "potential seed-cotton production" per plant by October 1 was on plat 3, which had been supplied with water sparingly.

The highest actual yield of seed cotton was produced on plat 1, on which the plants had been stimulated by comparatively early irriga-

tions to set more than half of their total number of bolls during the first half of the flowering season.

The data indicate that effort should be made to stimulate the setting of fruit to the fullest extent during the months of July and August, especially in areas frequently visited by comparatively early frosts, since the number of bolls set during this period largely determines the extent of the crop.

There are indications that an internal physiological reaction results from prolonged water stress in the plant tissues which tends to inhibit their response and recovery when more favorable conditions are restored during later development.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 1019

Contribution from the Bureau of Markets and Crop Estimates
H. C. TAYLOR, Chief

Washington, D. C. ▼ April 14, 1922

MARKETING BROOM CORN.

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USE AND IMPORTANCE OF CROP.

Broom corn is a comparatively small crop and has a limited use, therefore it has failed to command the attention of the marketing agencies which have played such an important part in developing efficient systems of distribution for the more important products. Broom corn is marketed to-day by much the same methods as those employed 70 years ago, but with the advent of regulatory measures, grading rules, and other means of bringing about a more just and economical distribution of important commodities, growers, dealers, and manufacturers find that the absence of similar advantages for broom corn leaves much to be desired in the development of better market practices.

In the manufacture of brooms, broom corn[1] has been replaced only to a very small extent by substitutes. Grass, rattan fiber, bristles,

[1] The term broom corn is applied to the growing crop, also to the brush or that part of the plant used in the manufacture of brooms. The words "brush" and "heads" usually mean the portion consisting of the "stem," "knuckle," and "fiber," the word knuckle applying particularly to that portion of the brush where the fiber is attached to the "stem." The stem is the uppermost portion of the stalk below the fiber, or the portion that is harvested with a fiber. (See plate I.) The "boot" or "sheath" is the leaf sheath that encircles the stem of the brush. "Hurl" as applied to broom corn includes brush of suitable color, fiber, and length for use on the outside of brooms. "Insides" and "covers" are the brush used for the interior of brooms. "Butting" is a process by which the butts of the broom corn are evened up. (See plate IV, fig. 1.)

broom weed, and, possibly, other commodities have been used to replace it with varying degrees of success, but usually the substitute has been worked in with the broom corn in manufacturing and has not entirely replaced it.

The fiber of broom corn has very little use except for broom making, but the demand for brooms has remained rather uniform over an extended period, and a limited quantity of the raw product finds a market each year. This quantity is roughly estimated at about 50,000 tons, and approximately 300,000 acres are necessary for its production. Substitutes for brooms have appeared on the market, but the increased population has tended to keep the demand stable.

Value of the broom corn crop and its importance in the States where extensively grown.[1]

State.	Year.	Acreage.	Average yield per acre.	Production.	Average farm price per ton Dec. 1.	Farm value Dec. 1.
			Pounds.	*Tons.*		
Illinois	1920	18,200	500	4,600	$175.00	$805,000
Missouri	1920	4,500	465	1,000	145.00	145,000
Kansas	1920	20,000	375	3,800	89.00	338,000
Texas	1920	33,000	230	3,800	118.00	448,000
Oklahoma	1920	105,500	324	17,100	129.00	2,206,000
Colorado	1920	7,000	370	1,300	70.00	91,000
New Mexico	1920	11,000	420	2,300	100.00	230,000
Total	1920	199,200	340.4	33,900	125.73	4,263,000
United States	1919	262,600	386.9	50,800	153.64	7,805,000
Do	1918	366,000	315.8	57,800	220.93	[2] 12,770,000
Do	1917	345,000	332	57,400	292.75	[2] 16,804,000
Do	1916	235,200	330	38,726	172.75	6,690,000
Do	1915	230,100	454	52,242	91.67	4,789,000

[1] Monthly Crop Reporter, vol. 6, No. 12, p. 139.
[2] The high cost of labor, the increased cost of machinery, and large Government contracts for brooms during the war are given as reasons for the noticeable increase during 1917 and 1918.

PREPARATION FOR MARKET.

Two varieties of broom corn are produced in the United States—Standard and Dwarf. The methods of cultivation are similar, but because of the peculiar difference in their growth, the tendency has been to adopt different methods of preparation for market. Success in handling either variety is dependent to a large extent on proper care during the harvesting period. Even with the most efficient systems of distribution it is impossible to overcome the handicap of an inferior product. A study, therefore, of the process of preparation becomes an important part of the analysis of the marketing situation. Methods of harvesting, thrashing, and curing broom corn have been discussed briefly in connection with the production of this

crop in previous publications of the Department of Agriculture,[2] but it is desired to bring out here a few of the principal points in these operations which have a direct bearing on the marketing of this commodity.

SELECTION OF BRUSH.

The selection of properly matured heads commands first attention. Broom corn is in the proper stage for harvest when the fiber is deep green from tip to knuckle. This stage may be reached when the head is in bloom or not until the seed is in the dough stage. If harvested too young the fiber will be pale green to white at the knuckle. This immature fiber lacks elasticity, shrivels perceptibly on curing, and presents an uninviting appearance when baled. Overripe brush is equally undesirable, for it becomes harsh and brittle and usually shows red or red specks, particularly if the harvest has been delayed on account of wet weather.

WHAT NOT TO HARVEST.

Preventable waste among manufacturers can be traced in many instances to the first steps in harvesting. Just what constitutes waste, however, is not easily determined, as certain kinds of brush that go to the trash pile in one factory are utilized by another. There are, however, some well-defined types generally considered not profitable to use. (See Pl. II.) These are "spikes," large center-stemmed brush, weather-stained "crooks," and extreme curly growth. Spikes, which are small, undeveloped heads with scant, short, and often immature fiber, are used by manufacturers, if at all, to stiffen the body of the broom. Their value in broom-making is limited, and many factories consider them a total waste. Heads having large center stems, especially those having no well-defined knuckles (Pl. II), add materially to the expense of working broom corn and their value in the harvest is very much questioned. "Crooks," or heads that are sharply curved just above the knuckle, while often of excellent fiber, are frequently not profitable to harvest. This depends upon the prevailing quality and market value of broom corn generally. In periods of low prices it seldom pays to gather them, because the price received is usually less than half that paid for good brush or similar fiber. If prices justify the cutting of crooks, they should be harvested and handled separately, or, at any rate, be removed from the bulk of the crop before being thrashed, because they interfere materially with the general thrashing. In certain sections curly growth is frequent. This growth is considered of little value, and "burly" heads which are both short and twisted

[2] Rothgeb, B. E. Dwarf Broom Corn, U. S. Department of Agriculture, Farmers Bulletin 768. Standard Broom Corn, U. S. Department of Agriculture, Farmers Bulletin 958.

should be left in the field. If the harvesting of broom corn is properly done there will be very little trash, such as leaves and boots, on the brush. In general, it may be said that anything unfit for use in the manufacture of brooms should, so far as practicable, be left in the fields.

THRASHING.

To command the best price, broom corn must be free from seed. The operation of removing the seed is variously termed seeding, scraping, or thrashing, and this phase of the preparation for market probably has been criticized more than any other. The value of the brush is materially affected by the quality of the work performed.

MACHINERY USED.

There are two kinds of thrashers—hand-fed and machine-fed. Essentially, a thrasher consists of a frame with one or two cylinders, the surface of which is equipped with teeth or spikes. If double cylinders are used, one is set above the other and they are run in opposite directions. Self or machine fed thrashers are so arranged that the broom corn is conducted to the cylinders by means of a toothed chain that runs at an angle with the cylinders in such a manner as to permit the brush to extend farther and farther between them as the brush is carried along. The seed from the tip portion is first removed and by the time the brush has been carried to the rear table the cylinders have scraped the seed from the entire length of the fiber. A power machine such as described (see fig. 3, page 10) with a crew of 20 men can thrash the brush from about 30 or 40 acres in one day. Hand machines are little used except for individual work. Such machines usually are of the one-cylinder type and are hand-made. In thrashing with this type the brush is held firmly with the hands and applied to the rapidly revolving cylinder.

Thrashing machines of either type, if run at the proper speed and operated with sufficient and competent help, will do good work. With hand-fed machines, if the broom corn has been delivered from the field in a satisfactory condition, there seems no reasonable excuse for poor thrashing, because the brush can be applied to the cylinder until all of the seed is removed. With power thrashers much broom corn is poorly thrashed. The principal causes may be summed up as follows: Improper handling of the crop prior to its thrashing, improper feeding, carelessness in operating thrasher, incompetent and insufficient help, windy weather during the thrashing period, night thrashing, and willingness on the part of interested parties to leave seed on the brush.

PRIOR PREPARATION IMPORTANT.

Close study reveals that much of the criticism of current practices in thrashing broom corn more properly belongs to the preparation

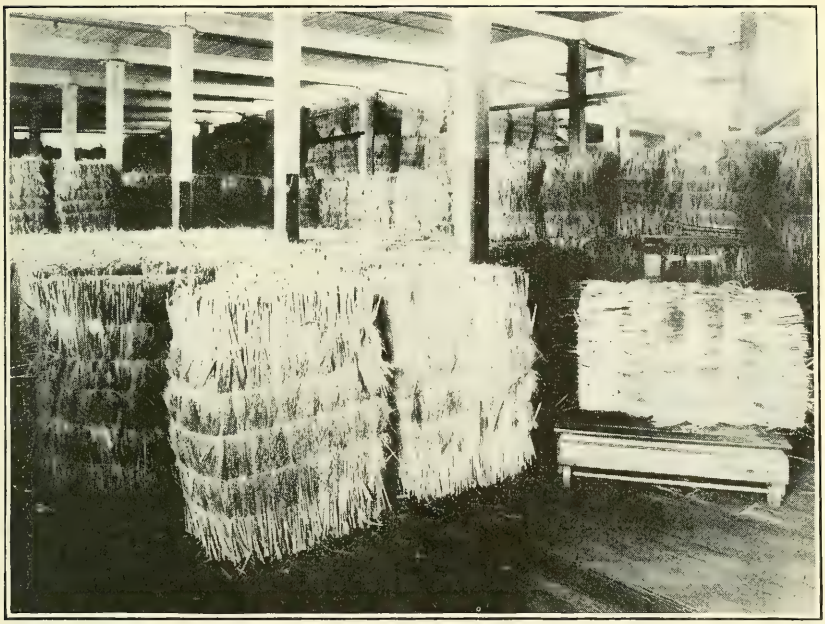
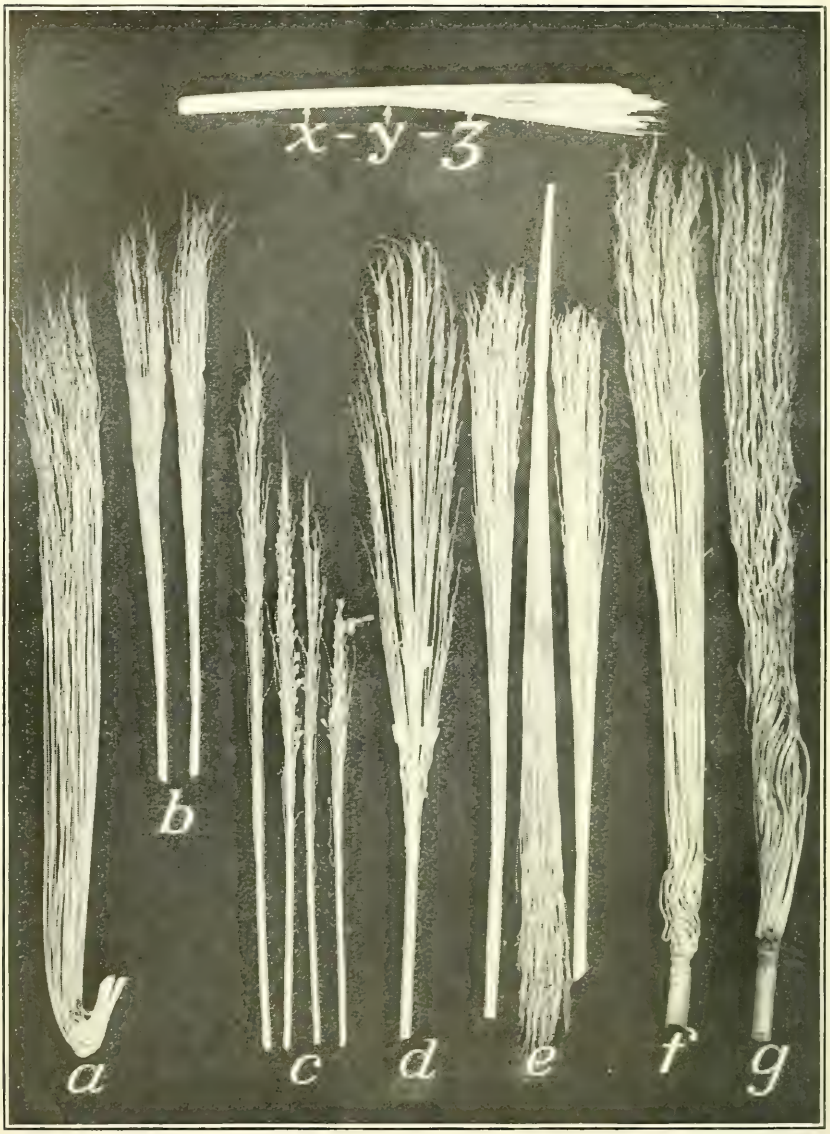


FIG. 1.—WELL-LIGHTED WAREHOUSE, SHOWING METHODS OF DISPLAYING BROOM CORN FOR SALE.

FIG. 2.—"OPEN-AIR" STORAGE AT COUNTRY SHIPPING POINTS.



GOOD AND POOR HEADS OF DWARF AND STANDARD BROOM CORN.

(*a*) A good grade of crooked; (*b*) high grade whisk stock; (*c*) group of spikes, worthless, but often harvested; (*d*) poorly tipped brush showing also a heavy undesirable center stem; (*e*) high grades of Standard and Dwarf, round straight fiber, full tipped with smooth well defined knuckles, no center stems; (*f*) objectionable curly growth but marketable; (*g*) worthless curly brush; (*x–y–z*) sectional view of brush showing (*x*) stem, (*y*) knuckle, (*z*) fiber.

prior to removing the seed. Improper thrashing induces great waste, but much of the waste in thrashing is unavoidable unless the brush has been delivered in a satisfactory condition. It is obviously impossible at this stage of preparation for market, for thrashing crews to take the time necessary to disentangle brush, or to remove foreign and worthless material, such as husks, surplus stalks, spikes, burly brush, and crooks. It is essential, therefore, that broom corn receive the proper attention prior to its thrashing.

PROPER FEEDING IMPORTANT.

The importance of feeding broom corn into the feeder chain properly should not be overlooked, because, once inserted, the brush passes through without giving further opportunity to retain or arrange it so as to remove any seed the cylinders fail to touch in the regular operation. In feeding, the brush should be arranged so that all seed to be removed must pass along not closer than 4 inches to the chain. Broom corn of ordinary length has little or no seed within 4 inches of the knuckle and this permits feeding so that the feeder chain may engage the fiber just above the knuckle, thus preserving the stems of the brush and preventing undue loss of brush, which sometimes occurs when the stem has been engaged by the feeder chain and crushed. The amount of brush fed should be uniform. The cylinders will remove the seed better if the layer of broom corn engaged is not too thick. Large handfuls crowded in the feeder chain "slug" the machine and decrease the speed for a moment and the central portions pass through poorly thrashed. Best results are obtained by having sufficient help to furnish the feeder a steady stream of brush about 2 inches deep and well butted.

OPERATING DEFICIENCIES.

Machinery for thrashing is simple in construction and is easily kept in proper condition, but it is often neglected and becomes the source of much waste and poorly thrashed broom corn. Bent cylinder teeth or the loss of teeth hinder proper thrashing and loose bolts are the forerunners of breakdowns, which cause loss of time to large crews, allow brush to become overripe, and result in much waste. The speed of the cylinder is an important factor in thrashing and any inattention, resulting in too low or too high a speed, is detrimental. Too low a speed results in the heads passing through without being sufficiently scraped. This is particularly true when the seed is immature or chaffy. Too high a speed removes with the seed the fine fiber on which it grows, destroying the full tip of the brush so much desired by all broom manufacturers.

No set rule can be given for the proper speed. It is governed entirely by the condition of the broom corn and the size of the cylinder.

A speed of 1,200 to 1,500 revolutions per minute is recommended for power machines by the manufacturers.

Much poorly thrashed broom corn results from insufficient and incompetent help. Instances are common where thrashing is undertaken with insufficient help to straighten the brush as fast as the thrasher will remove the seed. In the effort to supply the needed brush the proper butting of it is neglected, so that the feeder chain is not engaged properly and the brush either fails to come in contact with the cylinders or to engage the feeder chain at all and becomes waste in the seed pile.

HIGH WINDS DETRIMENTAL TO THRASHING.

High winds disarrange brush not only when being handled in the field but when being thrashed. They are particularly troublesome where thrashing is done from the rick. The dry broom corn is light in weight and unless amply protected is disarranged on the table. If it passes between the cylinders not properly butted, the heads that are disarranged frequently fail to come in contact with the cylinder teeth and pass through untouched. Tarpaulins stretched up on the side from which the wind blows are usually sufficient to overcome much of the trouble.

NIGHT THRASHING.

When there is a scarcity of thrashing machines or when the broom corn has matured rapidly, the danger of loss through overripe brush stimulates nightwork. Night thrashing usually results in work below the standard that is ordinarily expected from day thrashing, but it is generally practiced when the necessity demands and it can not always be avoided.

INTENTIONALLY LEAVING SEED ON THE BRUSH.

Willingness on the part of the interested parties to leave seed on the brush too often is the cause of unsatisfactory thrashing. Extensive inquiry indicates that about 25 per cent of the growers are indifferent to good thrashing. Instances have come to attention where, in order to increase the weight on sale, the grower has requested that the seed be left on the brush. Such an attitude tends to lower the standard in a district, and the practice should be condemned. It is a fallacy for growers to suppose that poor seeding means added profits to them by reason of the extra weight, for buyers are fully aware of the practice and adjust the condition by heavily discounting the price; so while growers may feel they have received more for their broom corn, in reality they have received less.

The results of poor thrashing are far-reaching. The seed has no value whatever to the manufacturer but adds to his cost of producing

brooms. If allowed to remain, it interferes also with the uniform dyeing of the brush. It must be removed at the factory with hand-fed thrashers before the manufacturing process can be completed. This results in a duplication of labor, and additional expense is entailed in hauling this waste material from the factory. The freight charges are increased on account of the seed which is shipped to market with the brush. These additional costs obviously lessen the profit derived from the industry and are reflected in lowered prices for the raw material.

CURING.

Climatic conditions have been largely responsible for the marked difference in the methods of curing the two varieties of broom corn. The Dwarf variety for the most part is grown in higher and drier altitudes than the Standard, and, owing to the limited rainfall, is less likely to be seriously damaged during the harvest. The possibility of ricking in the open and postponing the thrashing until other farm work demands less attention is inviting to growers in these sections and has been practiced rather extensively in preference to shed curing.

RICK CURING.

Rick curing is practiced extensively and is the preferred method where sheds are not available, but is far from satisfactory and frequently the losses sustained in one season from weather damage alone are as great as the cost of erecting suitable protection. Broom corn should be sheltered from sunlight and rain. Rick curing does not have these advantages and is not recommended where best results are desired. The brush must undergo a partial curing in the field, and if ricked too green it invariably molds. If the brush does not become weather-stained, the surface of the small piles bleaches more than the interior, and the color is not uniform. This is noticeable in the bale, which, when marketed, brings a lower price.

As a precaution against weather damage the entire rick should be thatched with broom-corn stalks or other material. When thus sheltered broom corn sustains comparatively little damage from weather unless severe storms occur. (See Pl. III, fig. 2.)

A method of outdoor curing which many consider much better than ordinary ricking is coming into use in some sections. A suitable frame for shelving the brush, similar in construction to that shown in figure 1, is provided. Layers of broom corn are placed between the slats, the lowest being filled first. A layer is next placed in the space provided just above, and so on, until the rack or frame is covered. By this method ample circulation of air is provided, thus permitting the shelving of corn that is comparatively green. With favorable weather the material is cured quickly.

SHED CURING.

The best method of curing both Standard and Dwarf broom corn, and at present the only method of curing which offers assurance of a uniformly colored, dependable product, is to place it under sheds. For the best grades, a pea-green color is essential, a bright pea-green color being evidence of care not only in harvesting but in curing. The lack of it is evidence that the crop is overripe, immature, bleached, or otherwise damaged. Pea-green brush, if of good fiber, desirable length, and well baled, is in best demand in all markets and commands the top price. To produce it suitable housing space must be provided, equipped with slats or shelves where the brush can be spread out thinly, permitting a circulation of air above and below each layer. The shelving is best made by using cross-section slats on which other slats are placed, forming shelves at intervals of about

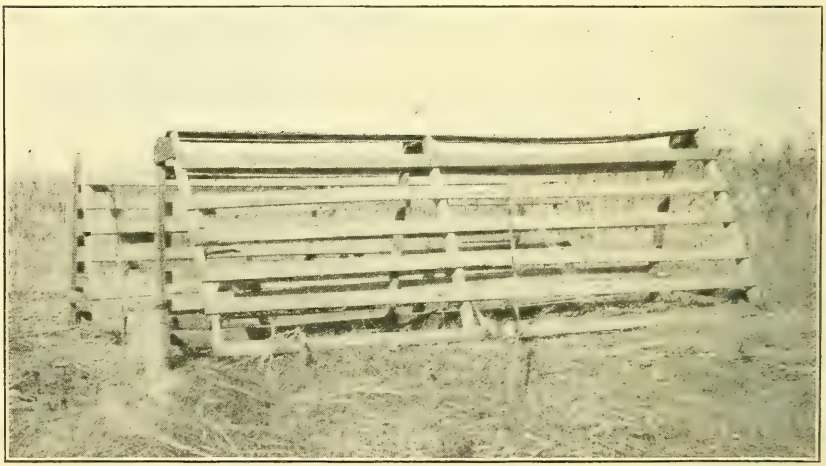


FIG. 1.—Rack on which broom corn is shelved in the open for curing.

4 inches. On these slats the brush is placed about 2 inches deep. Unless dry weather prevails during the time of curing the piling of brush more than 2 inches deep is likely to result in mold. As a precaution against loss the brush should be examined frequently to see that it is not heating, as damage from either heat or mold lowers the value appreciably.

Though open sheds are preferable for rapid curing, the damage from wind and rain often makes additional protection necessary. The ends and one side of curing sheds are sometimes sheeted with good results, and canvas that can be raised or lowered has proved effective in protecting the brush during storms. Since only about two weeks of favorable weather are necessary before broom corn can be "bulked," barns, cow sheds, etc., can be made to serve as curing places unless the crop is large, in which case a suitable shed made especially

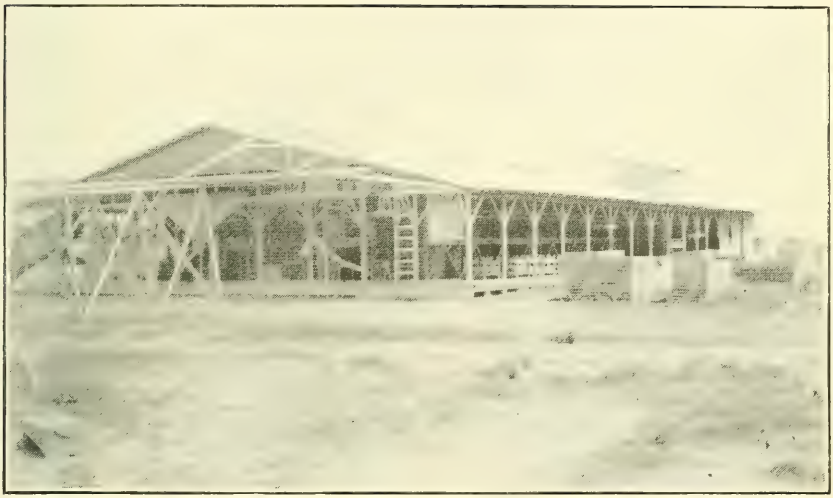


FIG. 1.—A MODEL KILN DRYING PLANT FOR CURING BROOM CORN.

FIG. 2.—A RICK OF DWARF BROOM CORN WELL PROTECTED WITH BROOM-CORN STALKS.

FIG. 1.—BALING BROOM CORN. PROPER METHOD OF "BUTTING" THE BRUSH.

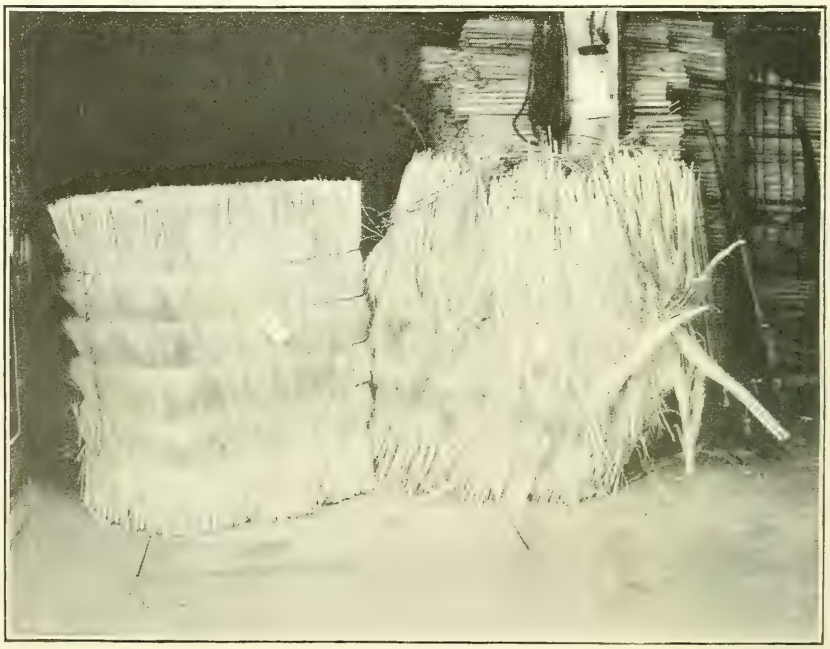


FIG. 2.—WELL AND POORLY BALED BROOM CORN ON ARRIVAL AT AN EASTERN MARKET.

for the purpose should be erected. A typical broom-corn curing shed is shown in figure 2.

Whatever the method employed in curing, the essential thing is to arrange the brush while green in thin layers away from rain and the direct rays of the sun and where winds will not disarrange it. It must be thoroughly dried. No attempt should be made to bale until the stems will break readily under pressure of the fingers.

KILN DRYING.

Another method of curing is kiln drying, which follows a wilting period of a day or two. This method is still in the experimental stage and as yet is confined to the districts in southern Texas. To facilitate quick drying a plan for artificially heating the broom corn is being perfected. A brief description of one of the plants will best serve to describe the process (see plate IV, fig. 1).

FIG. 2.—A typical curing shed for broom corn.

The drying room consists of an airtight compartment about 20 by 70 feet and 8 feet in height. This room is asbestos lined to retain the heat. Beneath the floor, throughout the length of the room, extend two large flues, through which hot air is conducted to openings in the floor, which permit the hot air to enter the drying room at designated places. At the top of the room at one end are openings to allow the air to return to the heating chamber.

The heating chamber, which contains several hundred feet of steam-heated pipe and is equipped with blowers, is connected with the flues that pass under the drying chamber and also with the return flues that carry the air back from the drying chamber. Thus there is provided a means for a complete circulation of heated air from the blowers, around the heating coils, into the drying chamber and back again to the blowers. Provision is made at the top of the

drying chamber for ventilation in case too high a temperature endangers the broom corn.

Trays are provided on which to place the green brush as soon as thrashed. These trays consist of frames with wire bottoms, which telescope into each other, forming tiers as high as desired. They are filled about 4 inches deep and placed one on top of the other on a truck, which is then rolled into the drying chamber. This process is continued until the entire chamber is filled. There is room in the drier for 28 trucks of trays each of which when filled contains about 200 to 400 pounds, depending on the dryness of the brush. The capacity of the drier is from 4 to 6 tons of broom corn. When the hot air has been applied from 6 to 12 hours the brush is ready for baling, whereas it takes from 12 to 15 days to dry broom corn in open sheds by the open-air method of curing.

FIG. 3.—Thrashing broom corn with power thrasher. Note the waste underfoot and the poorly shelved broom corn at the extreme left.

The operators claim that the following advantages besides others are procured through using a kiln for drying the corn: Delivery about 15 days earlier than with open-shed drying; better color because of ability to dry in wet weather, thereby saving crops that otherwise would spoil; elimination of moldy brush; and the production of a tougher fiber. They also claim that buyers will pay from $25 to $35 per ton more for the kiln-dried brush. The average cost of kiln drying brush at the plant described is estimated to be about $11 per ton.

BALING.

Better prices are obtained for well-baled broom corn than for brush of the same kind and grade that is poorly baled. The baler is filled with brush by hand. Small armfuls are placed alternately against each end until the baler is full (see Pl. IV, fig. 1). A crew of nine men with a horsepower baler can bale about 50 bales a day. The bale should be firmly packed, square with smooth ends devoid of protrud-

ing fiber, evenly and tightly tied with five strands of No. 9 wire, and preferably cross-tied with lighter-weight wire. Only well-cured and merchantable brush should be used, and as a matter of protection and appearance care should be exercised in having the brush well "butted" before it is placed in the bales.

STANDARD-SIZED BALES.

A standard bale of broom corn is 45 inches long, 26 inches wide, and 34 inches high. As found on the market, however, a bale usually is about as high as it is long and varies in weight from 300 to 425 pounds, depending on the fineness and quantity of brush used.

Bales of standard length and width load in cars without dead space, whereas odd-sized bales do not. Standard-sized bales are preferred because shippers are unable to load off-sized bales to the minimum load stipulated and are thus compelled to pay higher freight charges.

CROSS-TYING.

Since the bulk of the broom corn is shipped from country points to terminal markets and is often subjected to rough handling in transit, the regular method of baling is not always sufficient to insure its arrival at destination in good shape. Stocks that present an uninviting appearance on the sales floor usually command a lower price than do well-made bales of equal grade and quality. A comparison of the two bales in Plate IV, figure 2, clearly reveals the importance of care in preparing bales for shipment.

As a precaution against damage in handling, cross-tying has come into general use. The method employed is to connect the two opposite end wires of a bale with somewhat lighter wire than that used in baling to prevent the outside bale wires from slipping. Usually four cross-ties are used. They are placed at each of the four sides, preferably underneath all five of the bale wires. As the Dwarf variety has small stems it is more difficult to bale neatly than the Standard variety, the ends of the bales tending to taper somewhat. This variety, therefore, particularly needs cross-tying to prevent the outside wires from slipping.

If baled broom corn is not marketed immediately after being baled it should be stored in a dry place protected alike from the direct rays of the sun and from rainy weather.

MARKETING AT COUNTRY POINTS.

KINDS OF DEALERS.

It is practically impossible to classify the various broom corn dealers, because of the overlapping of the functions that each performs. A dealer, for instance, may be generally known as a resident

or local buyer. As such he has his home at some distributing point and purchases for cash the broom corn arriving on his market. If abnormal conditions develop in his territory he may be unable to obtain his requirements at home, so he goes to other districts to purchase. He then becomes a traveling buyer. Or possibly he may do what is generally termed wholesaling, but may be a retailer as well.

The term "commission man" is probably more confusing than any other, because it is applied to certain dealers who, on account of the many laws enacted to control the handling of farm products sold on commission, have changed their methods of doing business so that their activities do not come within the jurisdiction of these laws. Reference is made particularly to those who buy broom corn outright, and therefore become temporary owners of the brush, yet receive a stated commission on the transaction. These men are commonly termed "commission buyers."

Commission men, however, are generally understood to be dealers who receive broom corn to sell on a commission basis. They have no financial interest in the corn and act only as agents; consequently the term is made still more confusing when it develops that some commission or consignment merchants also purchase and sell for their own account. It will be seen, therefore, that a designation that may seem specific may develop to be one with decidedly arbitrary meaning.

WHOLESALE DEALERS.

The large wholesale dealers probably study market conditions more closely than other classes of buyers, and considerable importance is attached by the smaller and less influential dealers to their activities.

It is estimated that about one-half of the broom corn raised in this country is purchased at country points by these firms, the bulk being stored in immense warehouses and distributed throughout the year as needed by the various factories. Since it is necessary for them to carry large stocks over long periods of time, their success necessarily is measured by their ability to anticipate future market conditions and to avoid, in part at least, the hazardous speculation usually attending the marketing of this commodity. To do this, large amounts are expended each year in determining the probable acreage, yield, and quality, the general demand for brooms, and any other factors likely to indicate the trend of the future market prices.

Many of the wholesale dealers represent large financially responsible organizations that employ traveling buyers who keep their firms fully informed regarding prevailing conditions, in addition to buying. With such an organization it is possible for a firm to be in constant touch with conditions at all important shipping points and to direct the buying from a central office. The advantages are apparent.

When certain markets are glutted and weak, the buyers at those points may be instructed to purchase heavily, while other buyers for the firm are inactive at the markets where prices appear too high or where there is too much competition. The result of this method of purchasing is a much lower average buying price.

TRAVELING BUYERS.

While many buyers who travel are employed by large firms, the term "traveling buyer" is applied more particularly to those whose remuneration is on a commission basis. Their business is to supply the manufacturers with broom corn in carload lots direct from the producing sections. They might be termed wholesalers, but since in many cases every carload sale represents a complete transaction and often a "turnover" of all capital invested they are not generally so designated.

Traveling buyers usually procure orders in advance of purchase, either through advertising in trade journals or through manufacturers with whom they previously have had satisfactory dealings. Many manufacturers, not wishing to visit the producing sections themselves, employ these men to purchase to the best possible advantage the broom corn necessary to meet their requirements. Many traveling buyers have built up a very creditable business by close and careful buying, and where reasonably satisfactory purchases have been made they have retained old customers over a period of years. It should be clearly understood, however, that this kind of business is successful only when good business relations have been developed and when the particular needs of the manufacturer are well known from previous handling.

Though it is true that traveling buyers have their own cars, travel where and when they please, and have no office expense, clerk hire, taxes, nor insurance, there are a few things that greatly handicap them. Most important among these, especially during years of heavy movement, is lack of storage and shipping facilities.

LOCAL RESIDENT BUYERS.

Local resident buyers are the "old guard" in the buying of broom corn at country points. Where they have built up a business by fair dealing and close personal acquaintance with growers, traveling buyers find business decidedly competitive. This is particularly true where local buyers own ample storage facilities.

At most of the important country-point markets there are from two to five resident buyers. Their business, like that of the traveling buyer, is to supply manufacturers with broom corn direct from the field. The practice with most dealers is to procure orders and

then drive through the country, purchasing here and there in small lots and concentrating these purchases at some shipping point until a carlot shipment can be made. They then make the shipment and make a draft through the bank for the cost of the corn plus their profit. Local bankers often furnish resident dealers with their operating money. Where orders are not obtained in advance, broom corn is purchased, concentrated in storage, and held until prices are satisfactory or orders are obtained.

ONE-MAN MARKETS.

In extremely small towns and in a few of the larger ones there is frequently but one local shipper. As in hundreds of other towns, he usually handles the bulk of the mercantile business. He buys everything the farmers have to sell and sells everything the farmers need to buy, controls a bank or two, and, in a general way, realizes on nearly everything going out or coming in. He lends money on the crops and buys the bulk of them. When the marketing season is over, some farmers are satisfied but others may feel that advantage has been taken of them.

Where one buyer handles the bulk of the broom corn the market may be more or less monopolized. In studying these small markets it has been noted that traveling buyers on entering a market will first visit the local dealer. Frequently they find it to their advantage to buy, or arrange to have the corn they require purchased, on commission. This is natural, since the commission is very little if any in excess of what it would cost a traveling buyer to hire an automobile and spend several days going over territory with which he may not be familiar. Besides, he must bid up on the broom corn to get it at all, and he must see to the delivering, weighing, and shipping himself. The local buyer, knowing this, offers him a carload out of his warehouse as cheap or cheaper than he could go out and buy it. With the field clear the local buyer can and does buy cheaper.

Another method of keeping out buyers is to "bid up" on small crops here and there over a district. When the traveling buyer goes into the field he finds the broom corn held at a much higher figure than he is willing to pay and leaves the district without buying.

LARGE MANUFACTURERS.

The large manufacturers, as well as the large dealers, employ field men either on a commission or on a salary basis. With some of these large factories buying broom corn is a matter of speculation. The buyers retained in the field report conditions, and if it is felt that the conditions justify they buy a year's supply during the busy marketing season. This practice involves a large outlay of money, which is tied up in the business for the whole season.

SMALL MANUFACTURERS.

The bulk of the broom corn is used by small factories that are too small to keep a regular buyer in the field and yet are large enough to justify early purchasing. The small manufacturers often go to the producing sections and either purchase their supplies themselves or get resident or traveling buyers to purchase them. In either case the personal inspection of the broom corn at points of origin is the thing desired. The small manufacturer is usually a good bidder. He enters the field to buy his year's supply, which may amount to only two or three cars. Formerly he purchased from a dealer, paying the extra price for the privilege of being supplied when his needs demanded. With him it is a case of purchasing quickly with the least possible overhead expense and returning with his purchase to the factory. These buyers usually prefer a street market.

TIME OF MOVEMENT.

Broom corn is first available in Texas. The movement begins in the Rio Grande Valley usually between July 1 and 10. The season of heaviest movement from country points extends from this time until the Colorado broom corn moves in October.

Under present methods of marketing there seems to be a decided tendency among growers to turn this commodity into money as soon as baled. There are several reasons for this. Farmers, as a rule, borrow money to raise or harvest the crop. This usually is short-time paper, drawing 10 per cent interest. The banker is therefore financially interested and, while usually willing to extend credit, more frequently advises early selling, particularly if prices are at all favorable. If prices are decidedly unfavorable and large amounts have been lent to farmers, the banks often feel forced to protect their depositors by calling on the growers to liquidate their indebtedness. This they do by selling at whatever price they can obtain.

Uncertain trends of market prices make the holding of broom corn with a view to greater profits decidedly problematical. Farmers generally show little inclination to hold their product if it is possible to obtain what they consider a reasonable price. This tendency often prevents their receiving a fair price, since the markets are frequently glutted by their efforts to effect early sales. A glutted market is invariably a weak market, which reflects lower tendencies, and this often creates a fear of still lower prices and increased offerings—a condition favorable to dealers but decidedly unprofitable to growers.

Another factor which has stimulated early selling is the opportunity presented to growers to sell early in the season. As the first aim of all dealers and manufacturers is to purchase brush that meets their particular requirements, the importance of being in the field to buy

during the busy marketing season is obvious. By so doing they have opportunity of greater selection and are more likely to supply their needs at less overhead expense. This desire on the part of some forces the others to go to the fields early, so that few buyers are in evidence after the bulk of the crop has moved. Realizing this farmers sell early in the season if possible. The fact that a neighbor has accepted an offer on his broom corn often induces another to sell.

PRINCIPAL COUNTRY SHIPPING POINTS.

Limited quantities of broom corn are produced in about 40 States, but the commercial production during the last few years has been within the States of Oklahoma, Texas, Kansas, Colorado, New Mexico, and Illinois. (See table, page 2.)

Some of the principal marketing points in these States at present are as follows:

Arcola, Ill.	Fairview, Okla.	Mattoon, Ill.
Alice, Tex.	Guymon, Okla.	McAllen, Tex.
Beeville, Tex.	Holly, Colo.	Portales, N. Mex.
Charleston, Ill.	Laverne, Okla.	Shattuck, Okla.
Elk City, Okla.	Liberal, Kans.	Syracuse, Kans.
Elkhart, Kans.	Lindsay, Okla.	Texline, Tex.

OPENING THE MARKET.

In analyzing the factors affecting the probable prices of broom corn on the opening of a market it must be borne in mind that this commodity is not a staple like wheat, and that its commercial importance has not justified boards of trade at big market centers where the volume of business transacted makes possible daily market quotations as a basis of arriving at values; hence dealing in broom corn is attended with much speculation and there is usually a wide range of prices.

At the opening of the markets, which occurs in southern Texas in July, the uncertainty of future market conditions is greatest, and the probable prices become a matter of much conjecture and invariably continue to be so until they actually are established.

The probable production commands closest study, for on this depends the demand at the close of the season, particularly with reference to kind, that is, whether "hurl" or "insides." If it develops, for instance, that there is an extremely short crop, there will be an early demand and generous buying, which on the whole tends to raise the price.

The probable surplus or carryover of the last year's crop is a factor to be considered, and the kind of brush constituting the bulk of this surplus is especially important. For example, if manufacturers have large quantities of short brush toward the close of the

season and no long broom corn with which to work it up (a condition common with many in the spring of 1919), naturally there would be an urgent demand for hurl, particularly where factories have large contracts to fill, that would utilize all their short brush and enough long to work it. Under such conditions it is likely that the factories having contracts to fill would place orders with dealers for this long corn. Hundreds of factories might place similar orders, with the result that the various buyers would go to a new market with orders for long broom corn covering a wide range of prices, but all with definite instruction to purchase cautiously and as cheaply as possible.

Farmers, on the other hand, may have estimated the cost of raising their brush and may be willing to sell only at a much higher figure. The spread in ideas of prices on an opening market is often as much as $100 per ton. Naturally such a spread must be narrowed in order to effect a mutual agreement on prices, and to do so various tactics are resorted to.

Prior contracts between dealers and manufacturers sometimes determine opening prices, or dealers may have contracted from the growers in advance. Such contracting is purely speculative, the dealer simply taking a chance on what future conditions will develop.

Large dealers study conditions closely by sending representatives over the producing areas. The information obtained covers acreage planted compared with that of the previous year, year's crop outlook, approximate costs of production, and the like, and from this information they are able to arrive at a definite conclusion as to what prices should move the crop and thus undertake to open up the market at that figure.

Manufacturers in buying take into consideration the prevailing prices at which brooms can be sold and the future outlook generally. In almost every instance buyers, though possibly having some definite information by which they are guided in making purchases of limited quantities, buy sparingly so that the quantities first bought by any one firm have little influence in establishing definite market quotations.

This unsettled state of affairs may continue for several days or more, no one apparently willing to back his judgment by heavy buying. In the meantime, however, a number of small trades may have been made, principally to fill stress orders, or the local dealer may attempt to relieve the situation by paying good prices for a few small crops in order to stimulate a heavier movement of broom corn to market.

The disposition of the farmers to hold or to sell at the prices offered determines whether the market opens brisk or dull. With a movement started, prices move up or down according to the number of

buyers with orders, the disposition of manufacturers generally to buy or to wait, and the reluctance or anxiety of farmers to sell.

METHODS OF MARKETING.

In general, farmers market broom corn by one of two methods—through "street markets" or through "field buying" or selling on the farm. They may also market it by consigning direct to a commission house at a terminal point or by selling direct to local factories.

STREET MARKETS.

As a result of heavy production of broom corn in any locality, a street market frequently becomes the prevailing method of marketing. An open market of this kind seems best for establishing definite cash prices. There the manufacturer, the wholesale dealer, and the commission buyer are in evidence. Manufacturers may be purchasing their year's supply and wholesale dealers theirs, and since all that the wholesaler purchases must eventually go to the manufacturer, presumably at an advanced price, it appears that this type of market should be a competitive one. Dealers, too, who buy for the smaller manufacturers on a stipulated commission, find it to their advantage to purchase the brush necessary to meet their requirements as rapidly as possible and this increases the competition. Some of the outstanding features of a street market which are claimed as advantages by dealers are:

There is a saving in expense over field buying.

Farmers are better able to compare prices and determine for themselves the relative values of the different grades offered.

Farmers are better satisfied with prices obtained because they have the opinion of several buyers on the quality offered.

It is easier to examine and determine the quality on wagons.

Time is saved in buying.

The broom corn is in town ready to load and ship, so there is no danger of damage by rains before delivery after being purchased.

The farmers realize that a street market, such as that at Lindsay, Okla., attracts hundreds of buyers, but are not always so sure of the advantages. Some take the view that while sales are readily effected the methods practiced are questionable and fair prices are not obtained. Dealers are often accused of the practice known locally as "sweating." The farmers, for example, have driven in from long distances. Some perhaps have come 20 miles over the hot, dusty roads. On arrival they find an indifference prevailing among dealers, who may stroll leisurely about looking at the offerings, loiter around the hotel lobbies, or sit on the curb whittling or discussing the topics of the day, doing anything in fact but bidding on broom corn. The street in the meantime may be lined

with loads of brush with but few sales effected. Late in the day many farmers, wishing to sell and go home, are prompted to solicit bids. The bids, if obtained, are unsatisfactory and are seldom raised. The farmers get discouraged and take the best offer that has been made rather than spend another day on the market, especially when they have no assurance of a higher price. This depressed market condition, which actually exists on many days, is explained by the fact that the dealers are there to buy, but lack orders or they may have orders for kinds not being generally offered. Prices, too, being paid by some may be higher than those at which others have authority to buy. The "sweating" is a condition often experienced,

FIG. 4.—A busy day on a street market at Lindsay, Okla.

but it is generally felt by farmers that the process is a premeditated endeavor among buyers to effect big savings.

In the Lindsay district many farmers arrange with their neighbors to assist in hauling and it is not uncommon to see several loads of broom corn representing the entire crop of one grower on the streets of this market at one time. (See fig. 4.) Some growers think they sell to better advantage this way, especially if there is enough to make a carload.

During the busy season the streets are well filled by 10 o'clock in the morning and often before that time. In fact, many haul at night or late in the afternoon in order to be on the market early the following day. The choice of locations where buyers are more likely to give their loads attention may be a cause for early hauling at Lindsay, but in most street markets the location is of minor importance.

On busy days buyers are everywhere in evidence, passing around from wagon to wagon examining the bales and frequently examining the corn by sampling or "pulling" the brush. Usually each buyer has some particular kind in mind that he is especially anxious to obtain to fill certain orders he may have, or, if he is buying for speculation, because of a known shortage of a certain kind. For example, a buyer may have an order to purchase a carload of "good medium-grade brush running strong to hurl" or a car of "fancy hurl" and may examine perhaps a dozen or more loads before finding what he wants. If it is not on the market, he may make conservative bids on crops not especially desired, but which he would purchase if he could obtain them cheaply enough.

When a dealer desires to bid on a certain lot of broom corn, it is common practice to ask the owner what offer he has had on it, and the information usually is obtained. The dealer then will probably make an offer. If the farmer thinks that it is as much as he will be able to obtain he may sell, but more often he waits for other bids, particularly if it is early in the day or his broom corn is of especially good quality. An offer made by a buyer is considered binding for the day unless it is indicated that the bid shall not "stand," but markets differ in this respect, the practice in any one market governing no other. If a bid is raised, it is usually by $5 a ton.

Farmers as a rule have little idea what their broom corn will bring when they haul it to market except as they are able to judge from the sales being made or from what their neighbors may have received. The sale price depends entirely upon what a buyer is willing to give. Buyers, while better informed on conditions, usually have no definite information on the value of broom corn. The dealers who buy on a commission basis are guided by prevailing sales and by specific orders they may have to fill for manufacturers, and they make bids accordingly. These orders frequently specify "Buy at the best possible price," or "Buy at not to exceed so many dollars per ton." It is quite natural in such instances that in order to hold future business they purchase as cheaply as competition will allow. Buyers sent out by manufacturers usually are not restricted as to price, but, like the commission dealer, try to purchase as cheaply as possible. It is natural to conclude, therefore, that a glutted market ripens the opportunity for dealers to beat down prices, while if there are but few offerings of a dependable grade these will meet with ready sale at a possible advance in price.

The broom corn offered on a street market, like grain and other farm products, is for cash, and settlement is effected in full at the time of sale. Sometimes a crop may be bought and payment deferred until all is delivered, but this is done only as a matter of convenience between buyer and seller.

Bale weights and wagon-scale weights are used, depending somewhat on where the broom corn is marketed. At points where marketing is extensive the bales are weighed singly on small platform scales and the individual weights recorded. The total weight is then found and settlement made at the price stipulated. Wagon scales are employed more generally in smaller markets or at shipping points where the broom corn is hauled directly to cars for shipment. Bale weights have proved more satisfactory at country points than weights obtained from weighing the entire load, yet a great deal of the broom corn is still weighed by the load. Wagon scales are used generally for grain, live stock, and other farm products and are conveniently located at nearly all shipping points. Their use for weighing broom corn has become general except at points where this commodity is extensively handled through warehouses. While well-regulated wagon scales render efficient service, the variations are often the cause of much contention.

Platform scales are of especial advantage because bale weights are desired. In making shipments it is customary to place a tag on each bale, showing from whom it is purchased, together with the weight, so that any irregularities that may develop later may be traced. Weighing on wagon scales, of course, gives only the net weight of the load, which makes reweighing of each of the bales necessary if any irregularities in the individual bale weights are to be found.

Buyers on a street market invariably judge broom corn by sampling. The three essential factors considered are length, color, and fiber. The custom is to pull from the various bales of each load enough brush to have a representative sample of the quality of the load in question (a good-sized handful usually is obtained). This is then inspected, taking into consideration the factors mentioned, the percentage of each kind obtained, and the general quality of the offering with regard to baling and freeness from trash and seed. The classification and sampling of broom corn are discussed more fully on page 25.

FIELD BUYING.

Field buying is extensively practiced in all districts, whether or not street markets are operated. Because of the long distance broom corn must be hauled in some sections, or the uncertainty of effecting satisfactory sales at shipping points, or unsatisfactory street markets, many farmers prefer to sell on the farms, and many dealers go out into the country to buy.

While devoid of competition, this method often results in more satisfaction to the growers, for the reason that they feel themselves to be masters of the situation. It is generally felt, too, that the incentive to buy is greater when the dealers drive through the coun-

try; in fact, many growers think that buyers drive out for broom corn only when they need it. While this idea may influence the belief that the demand justifies holding for higher prices, it is not necessarily true. A buyer may have any or all of the following considerations in mind:

The obtaining of information on the quantities yet unsold and the general quality.

Opportunity of examining the brush at the time of baling, or before, in order to determine the quality more accurately.

Purchasing entire crops, whereas on street markets only a part probably would be offered.

More time for making careful examination of prospective purchases than street markets afford.

The obtaining of exceptionally good brush held off the street market.

The purchase for future delivery on account of car shortage or in order to secure uniform loading of cars.

Field buying is practiced extensively by traveling buyers. They usually select some shipping point for headquarters close to the section in which they wish to operate and drive from farm to farm. The manner of dealing in the country for the most part is the same as on a street market, except that there is more opportunity to exchange views relative to trades. All bales are carefully inspected and enough brush "pulled" to form an opinion as to the quality.

It is customary for a field buyer to make a bid. If the farmer refuses the offer, the buyer seldom will let a bid "stand" good for a later date. This leaves the transaction open—a condition that invites the grower to see the buyer again before selling to some one else.

Buying broom corn by this method is usually expensive. In certain sections where Dwarf is grown the territory traveled covers a wide area. Often only a few bales are obtained in one place or the kinds wanted may be widely scattered. Or perhaps the price offered is not inviting to growers and little is obtained. Sometimes several buyers will traverse the same territory with practically the same results before the crop is moved.

Often, too, trouble is experienced in concentrating the broom corn after it has been purchased. Some farmers sell, but later, on account of higher bids, may not deliver, which means an extra trip into the country to replace what is lacking on shipping day. Or the buyer may have purchased a crop not yet baled, or an estimated quantity, and if the market declines all of it and possibly some of a neighbor's crop may be delivered.

CONSIGNMENTS.

The methods of consigning broom corn differ little from those used with other farm products. It is shipped to a commission merchant at a terminal market, who in turn finds a purchaser and remits

the gross returns minus the commission for selling and other charges. Many factors enter into broom corn consignments that are not fully understood and cause the business generally to receive much unjust criticism.

Primarily the consigning of broom corn is the result of unsatisfactory home markets. When a farmer consigns his product to a distant market usually he expects more than the home market offers and blames the commission merchant if the returns do not measure up to his expectation. He has little or no basis on which to arrive at the value of his broom corn. He can only compare sales made in his territory with the prices he received, or compare quotations printed in trade journals or daily papers. Either would be of little real value. Quotations in daily papers are often found to run for weeks without change, to contain only indefinite descriptions, and, at best, to indicate only broadly-prevailing prices. As a result they do not furnish a satisfactory basis for comparison. Furthermore, these quotations represent selling prices, f. o. b. terminal points, and do not take into account values at country points. They are often grossly inaccurate, yet are the prices at which consignments are expected to sell. It is difficult even for trade journals to give useful quotations because of the lack of established grades.

Although consignments are often unsatisfactory, the price received may be the best obtainable. From a marketing standpoint there seems to be no good reason why the farmer should not receive a fair return on a consignment. If properly handled, it should sell on its merits. Opportunities for selling are frequent, for in all big markets to which consignments move the warehouses are visited by many dealers who have come for the purpose of buying and who expect to pay a fair price.

Some of the more important points to be considered in analyzing the situation are: (*a*) In periods of overproduction, consignments of broom corn are likely to represent the bulk of the carryover; (*b*) shippers often fail to load uniformly; (*c*) the bulk of the consigned broom corn is usually of a low grade, which brings about slow sales; (*d*) heavy consignments weaken prices; (*e*) the bulk of the trade is usually supplied before consigned broom corn is available; (*f*) dealers may be forced to buy at lower prices to compete with consignments; (*g*) growers do not take into account extra expense of holding and increased cost of selling; and (*h*) shipments are sometimes made to unreliable commission men.

In periods of known overproduction there is not the urgent demand for early selection that prevails when broom corn is scarce and low, and medium grade brush, such as constitutes the bulk of consignments, is a drug on the market. Manufacturers and dealers feel that this class of broom corn can be purchased at any time; hence

the lower grades are "slow sale" and are carried along from month to month with accruing storage, insurance, and interest, to be deducted later when returns are made. If stocks are carried for a long time, they come into competition with the new crop, which further depresses the price. The consignor, however, still holds for a high price, so it is carried over as "surplus" or as broom corn not needed at all. The consignor in the meantime is impatiently waiting for returns at prices higher than he could have obtained when the demand was better. Dealers, knowing the prevailing conditions (for example, that there is an overproduction), sell and take their loss. The commission merchant advises similar action, but without avail. In the course of time the handling charges make all chances of profit impossible and the grower finally sells for what he can get.

Lack of uniform loading in making consignments has been a factor in bringing unsatisfactory prices. In shipping many put every grade, ranging from "junk" to "choice," in one car. Later the entire car may be sold by striking an average. Thus the good brush is sacrificed to sell the poor and the results are unsatisfactory.

Heavy consignments tend to lower prices. When terminal markets have large stocks of consigned brush, commission men feel that they must be moved at some price and urge selling. The bulk of the supplies needed by manufactures is purchased early from the Standard districts, and the western stocks, which represent the bulk of the consignments, often come on the market too late for the best demand and must be sacrificed to effect quick sales.

Dealers in purchasing in the field take into account the fact that heavy consignments probably will be made and many claim that they are forced to purchase more cheaply in the field in anticipation of future declines.

Shipping to unreliable commission men has been unsatisfactory. For example, a grower may consign a car to a commission man who also buys broom corn for himself. The consigned brush, of course, is placed on the sales floor in competition with that owned by the commission man. Naturally if a liberal buyer comes to purchase it is a temptation to the dealer to push the sale of his own broom corn first and let the consigned corn remain for the less anxious customer.

Cases have come to attention where, after considerable correspondence between the local dealer and the commission man, the local dealer received a commission, unknown to the grower, on a particular consignment made because of unsatisfactory local offers.

In justice to the terminal commission men, it must be said that the returns from many consignments are satisfactory, and that in the case of many which have been unsatisfactory, offers were received by growers which would have netted them a profit, but they refused

a fair price only to be forced later by natural declines to accept a lower one.

Commission men encounter some serious difficulties. It is customary to make advances to the farmers in order to meet the obligations incurred by them in the growing and harvesting of the crop. These loans are secured by the value of the broom corn only, and this does not always prove to be adequate protection. When serious breaks in the market force prices to very low levels, it is difficult and sometimes impossible to collect from farmers the balances due on account of the advances made to them. A general feeling of distrust toward commission men makes it difficult for them to render satisfactory service.

SELLING TO LOCAL FACTORIES.

The quantity of broom corn sold to local factories by farmers is insignificant compared with the quantity sold to dealers. At many distributing points small manufacturing concerns operate possibly two or three winding machines, but more frequently some individual has a small plant of his own. By being on the ground he is able to obtain broken lots, parts of bales, or bundles at his own price. Although whole bales are also purchased, this is an outlet to the farmers for the small broken lots which ordinarily are not very salable.

SAMPLING.

A number of factors entering into the proper classification of broom corn must be considered in sampling. Besides the important items of fiber, length, and color, there are others, such as the condition of the tip, brittleness, curly growth, seed on the brush, and general condition and appearance of the bale. It is difficult to determine how much each of these affects the value. A manufacturer, for example, when he buys a car of this commodity, must expect to receive every kind of brush. One kind usually predominates, but the variations necessarily are many.

Fiber is thought by some manufacturers to be of first importance. The fineness, uniformity of size, and wearing qualities receive due consideration. Those familiar with broom corn, however, are aware that pea-green brush has the most vitality and pliability and that the bleached brush has less vitality and is more brittle.

Color is an important factor in broom corn, the pea-green being the most desirable in appearance and usually in wearing qualities. Stained broom corn has no place in a fancy broom, as it is objectionable both in appearance and in wearing qualities.

Length is important in so far as it determines the use to which the brush can economically be put. Brooms are designed so as to use the greatest amount of brush with the least waste and therefore

broom corn is closely "sized" with this in view. The large number of lengths prevalent in all broom corn has led to the manufacture of brooms of several lengths.

Spikes are objectionable as a rule. Some factories, however, use some to give a "body" to the broom, the spike part of the brush not coming below the sewing. Just which spikes are valuable is difficult to determine.

Curly broom corn is very objectionable, being both undesirable in appearance and of poor quality. The prevalence of this kind of corn in bales must be carefully noted.

Brittleness is a quality that must also be considered in sampling. The use of brittle brush is restricted largely to "insides" because in manufacturing, "turn-overs" and "outsides" require bending, and brittle brush will not well withstand this usage.

The tip of broom corn is given careful consideration in selecting brush. Brush "stripped" in thrashing is scant-tipped and its value is lowered. Some brush is poorly tipped naturally, and therefore contains a low percentage of hurl. Full-tipped brush makes a full-tipped broom, as the ends are full-fibered and make a good body at the end when clipped.

Since it is upon the sample obtained that a buyer is supposed to base his bid, it is often misleading to note the price offered. It is well known that one accustomed to sampling broom corn can "pull" almost any grade of brush desired and often this is done intentionally. A low-grade sample is sometimes pulled to justify a low bid. Pulling low-grade samples may induce the grower to accept a lower bid, or may influence another buyer's bid, but has little weight if another buyer is really interested, as every buyer samples all corn purchased.

On the other hand, close sampling is necessary to discover some unfair practices. Damaged bales may be placed on the load with the damaged portion hidden from view or not easily accessible or the thrashing may have been poorly done. Broom corn may have been baled too green, or may be shelf-burned. Unless care be used in sampling, these factors may be overlooked.

COUNTRY STORAGE.

Storage facilities, while not always essential to the successful marketing of broom corn at country points, are very desirable and have a marked bearing on the movement of the crop. In localities where there is heavy rainfall during the marketing season, much damage occurs from lack of such facilities, while in sections where exposure is not considered especially detrimental, conditions would be much improved if storage houses were more generally used. In the terminal markets storage facilities are essential.

In almost all sections where the Standard variety of broom corn is grown, curing sheds (see fig. 2) are made available for the brush as baled. Here it remains well protected, especially when the sheds are boarded up on the sides most exposed to storms. While such sheds are for temporary protection only, they may be the factor which determines whether brush shall be of high or low quality, since proper care at this stage of preparation is very important.

In striking contrast are the storage facilities in the Dwarf producing sections. "Open-air" storage is the prevailing method in certain sections and is cheap, convenient, and often satisfactory for concentrating this commodity pending shipment. Open-air storage can not be recommended, but it is practiced extensively by farmers and shippers where rainfall generally is light and where no special attention has been given to shed curing. The actual loss on account of this practice alone over a period of years is much less than is ordinarily supposed, for the brush often is not strictly first class when baled. Western Dwarf is much more inclined to turn red than is Standard. The growth often is not uniform and ordinarily does not contain the high percentage of hurl that the eastern sections produce; and since "insides" generally need not be the perfect brush expected for the "outsides" of fancy brooms, the material meets the demand for a medium-grade product. The fact that "open-air" storage is inexpensive prompts many to hesitate about building expensive sheds or warehouses when they are not seriously inconvenienced by not having them. Serious losses, however, occur when unfavorable weather does come, and the experience of western growers in the season of 1920 will undoubtedly cause many to discontinue the practice of taking chances when a suitable protection will insure them against losses such as were then sustained.

Open-air storage at shipping points (see Pl. I, fig. 2) is also common in the Dwarf sections. At Elkhart, Kans., one of the largest country-point markets, no pretense is made of housing broom corn in warehouses, and the methods used at this market are typical of those generally employed. Hundreds of bales are piled on the ground, where they remain in the open until cars are procured for shipping to terminal markets. Unfavorable weather during this time is detrimental and interferes materially in shipping.

There are few country-point markets where warehouses are available for storing broom corn. The bulk is bought for shipment as soon as cars can be procured, and if there is no place to store it is kept on the farms until it can be shipped. The fact that storage is needed only for temporary use has discouraged the building of expensive warehouses, especially if they can not be utilized for other purposes throughout the year. This has been found a serious

handicap to traveling buyers, who may wish to hold small purchases over longer periods than ordinarily needed to secure cars. Local dealers avoid this trouble by having the broom corn hauled to points where they have storage. At most shipping points the available storage ranges from 5 to 20 cars in capacity and is owned largely by local dealers.

At Lindsay, Okla., facilities are available for handling about 300 cars. The warehouses are used chiefly for handling the broom corn bought by the firms who own them. They also store temporarily for others, the handling charges being $5 per ton, which includes storage for 30 days. Patrons carry their own insurance. During the busy marketing season the storage there is entirely inadequate, and when buyers are not able to obtain cars they often pile the bales on the ground. This has proved a costly venture at times, as rains there are frequent and severe and very damaging to the fine pea-green quality marketed in that section.

It frequently happens during the busy marketing season of broom corn that cars serve as temporary storage. At congested shipping centers the arrival of a few "empties" is often the occasion of arguments among dealers to determine prior shipping rights. To obtain a car is particularly advantageous, since loading can be begun and the car held, even on demurrage, until filled. By putting a few bales in, a dealer obtains grounds for an argument for a prior right and often this is done intentionally where cars are difficult to obtain. Such use of cars should be discouraged so long as the supply of rolling stock is not equal to the general demand.

TRANSPORTATION.

In years past the bulk of broom corn was produced in New York, Ohio, Illinois, and others of the more densely populated States, and manufacturers found it practicable to operate in the producing areas. Since then production has shifted west and transportation has necessarily become one of the big factors in its marketing. Approximately 5,000 cars find their way from producing sections to the various States. A portion of the crop goes to the west coast and some to Cuba, but the greater part moves east.

With the exception of the coastwise shipments from Galveston, the crop is handled by rail, and since broom corn is not perishable the crop moves in box cars by slow freight.

METHODS OF LOADING AT COUNTRY POINTS.

Figure 5 illustrates the method of loading cars from wagons. Where warehouses are not available farmers after weighing, drive directly to the cars. The buyer usually hires two extra men and the grower completes the crew. After "up-ending" the bales

through the car door, men with hooks place the bales at either end of the car. On these are placed a second tier, until the car has been filled. For a 36-foot car, 64 to 72 bales are required, depending on the size of the bales. Care is necessary in handling bales not cross-tied to avoid pulling the end wires off, thus injuring their appearance or making reconditioning necessary at destination.

At more extensive shipping points there is usually constructed on a sidetrack a platform the top of which is even with the floor of the car. The broom corn when hauled by farmers is dumped on the platform and trucked into the cars. This method saves much labor and permits loading with less damage to the bales. Where warehouses are available, the bales are weighed and tagged when unloaded and are either stored or trucked into the cars from the platform.

FIG. 5.—Loading cars with broom corn from wagons at country shipping points.

CHANNELS OF TRAFFIC.

While the general movement from producing to consuming points is more or less fixed, there are no regular channels through which the broom corn of any particular crop may be expected to move, the destination depending entirely on who purchases it. For example, a firm in the East may want annually 100 cars of a certain kind of brush. One season it may have been obtained in Illinois while the next year Oklahoma may have produced the kind desired, or perhaps it could be obtained from the Rio Grande Valley to better advantage. Again, certain large contracts for brooms may have been secured by firms in Chicago one year and in Baltimore the next. Thus it is seen that the movement may be entirely different from year to year.

Broadly speaking, however, it may be said that broom corn moves east from the producing sections of the Southwest, as does also the bulk of the Illinois crop. Investigations indicate that about 75 per cent of the crop west of the Mississippi moves through the Kansas City and St. Louis gateways, a large part of which moves via Wichita, Kans., for diversion. It is estimated that about 15 per cent could move to advantage via Memphis, Tenn., and Galveston, Tex., for distribution to southeastern sections. Galveston appears to be very favorably located for handling coastwise shipments from Texas and Oklahoma. Much of the Oklahoma crop, however, moves east via Wichita to Chicago and interior points, because of the present importance of Wichita as a concentration and diversion point.

Practically all movement from country points is in carload lots, and only during the last of the marketing season are less than carload shipments made. At that time buyers are sometimes unable to obtain carloads at certain points, and consignments are made to neighboring factories by the growers.

PRINCIPAL TERMINAL AND MANUFACTURING POINTS.

Most of the principal terminal and manufacturing centers to which broom corn is shipped in carload lots are as follows:

Amsterdam, N. Y.	Lincoln, Nebr.	Philadelphia, Pa.
Atlanta, Ga.	Mattoon, Ill.	Pittsburgh, Pa.
Baltimore, Md.	Memphis, Tenn.	San Francisco, Calif.
Chicago, Ill.	New Orleans, La.	Seattle, Wash.
Cincinnati, Ohio.	New York, N. Y.	St. Louis, Mo.
Cleveland, Ohio.	Ogden, Utah.	Tampa, Fla.
Davenport, Iowa.	Oklahoma City, Okla.	Wichita, Kans.
Indianapolis, Ind.	Paris, Ill.	

The bulk of the broom corn grown each year comes to these markets. Large manufacturers frequently find it to their advantage to concentrate their purchases there until needed, but stocks of dealers find their way to the sales floors, from which points they are distributed throughout the year in carload and less than carload shipments to factories.

The principal country and terminal markets and manufacturing centers to which large quantities move are shown in the accompanying map (fig. 6).

COOPERATIVE MARKETING.

The success attending cooperative activities in connection with the marketing of broom corn has so far been somewhat disappointing to growers. Perhaps the greatest cooperative activity has been in the Rio Grande Valley of Texas. Development in the broom corn business in this district has been rapid. High prices stimulated

heavy production, and the alluring possibilities of producing two and perhaps three crops a year with one planting induced many to enter the business on a large scale. During the war prices were high and the business prospered to such an extent that extensive preparations were made cooperatively to provide for every convenience that might assist in putting the brush on the market in the best possible manner. Among other things, warehouses were provided. Kiln-drying plants were constructed to provide a means for curing and handling broom corn in wet weather and to enable the growers to place their brush on the market at least 15 days earlier than by shed or open air curing.

The associations extended their activities to the cooperative selling of broom corn and in fact played an important part in the mar-

FIG. 6.—Map showing country shipping points, factories, and factories and terminal distributing points in the broom-corn industry.

keting of the southern Texas crops. They have not met with the success the producers anticipated, however, and in a number of cases the associations have ceased to function. Inefficient management and costly experiments in developing facilities for handling the crop are given as the principal causes for this condition rather than any inherent weakness in the system. Much good might have resulted if the organizations had been founded on a good, substantial basis and had been managed properly.

In New Mexico some years ago a movement was launched to organize a number of cooperative marketing associations among the broom-corn growers of that State. This movement was prompted by the unsatisfactory marketing conditions then existing and by the feeling that the marketing of broom corn at that time was under the control of a few speculative interests who operated to suit themselves.

The State marketing agent undertook to assist the farmers in formulating a plan for marketing this commodity, but for various reasons the growers did not take readily to the plan and the matter was dropped.

Notwithstanding the fact that up to the present time very little has been accomplished, there is an apparent desire on the part of many growers in the different producing districts in the different States to handle the broom-corn crop on a cooperative basis and the time appears to be rapidly approaching when some definite steps again will be taken with that end in view. The growers, however, realize that there are many difficulties to be overcome.

A good part of the service rendered to their companies by traveling buyers, and the consequent expense, no doubt, could be eliminated and substantial savings made by the organization of cooperative marketing associations. By working together on a cooperative basis the growers would be able to provide for themselves warehouses and storage facilities, and with these facilities assemble the brush in quantities at convenient central points. A competent sales manager could be employed to market the brush, and in this way much of the existing disastrous competition would be eliminated and much of the service now being performed by itinerant buyers could be abolished. The evident lack of reliable market information and proper understanding of market grades and standards has placed the growers at a great disadvantage, and unscrupulous buyers have frequently taken advantage of this situation.

It is believed that properly organized cooperative associations would be of material assistance in solving many local marketing problems encountered under the prevailing systems. Cooperative associations efficiently managed can obtain and use for their members reliable market information. They can assist in the establishment and maintenance of proper market grades and standards and in the more intelligent preparation of brush for market. In fact, it should be possible for them to obtain for the broom-corn growers more nearly the true market value of their brush.

In considering the formation of a cooperative marketing association it is essential that a careful study of the local situation be made. Among other things it is vital that there should be a sufficient volume of business available to justify the existence of an organization [3] and the employment of a competent manager. There should be a definite need for such an association in a community or district, and the mental attitude of the growers should be favorable toward an undertaking of this character. Otherwise the future loyalty of the members will be doubtful.

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[3] A suggested form of by-laws may be obtained from the Bureau of Markets and Crop Estimates, Department of Agriculture, Washington, D. C.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 1020

Contribution from
the Office of Farm Management and Farm Economics
G. W. FORSTER, Acting Chief

Washington, D. C. ▼ April 12, 1922

HARVEST LABOR PROBLEMS IN THE WHEAT BELT.

By D. D. Lescohier, *Collaborator.*

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SCOPE OF THE INVESTIGATION.

The small-grain harvest of the area lying between the Mississippi River and the arid districts east of the Rocky Mountains, from Texas to the Canadian border, is one of the most dramatic episodes in the economic life of the United States. Each year it calls more than 100,000 men from various parts of the country to aid in harvesting, thrashing, and storing or shipping nearly 450,000,000 bushels of wheat and 600,000,000 bushels of other small grains (Tables 1 and 2). It is more than a local venture; it is a national enterprise. Not only the people, resident or transient, who cut, shock, and thrash the grain, but the entire country feels its effects. Because of this and because farm-labor problems in general are becoming more urgent, data on labor conditions throughout the wheat belt in the harvest season of 1920 were collected by the United States Department of Agriculture.

Most of the information presented in this bulletin was obtained by field agents of the office of Farm Management and Farm Economics, who interviewed nearly 3,000 harvest hands, many farmers, county agricultural agents, employment officials, chamber of commerce secretaries, bankers, merchants, and other citizens in the harvest area of Oklahoma, Kansas, Nebraska, Iowa, and the Dakotas.[1]

[1] The author wishes to acknowledge the assistance given by A. L. Barkman, in charge of the United States Employment Service at Kansas City, Mo.; A. C. Albert, in charge of the State free employment office at Sioux City, Iowa; and E. L. Rhoades, farm management demonstrator, at Manhattan, Kans. The cooperation of county agents, bankers, local employment offices, and many other persons and organizations has added greatly to the value of this report.

The investigation was confined to the wheat area of the central part of the American continent, the so-called Big Wheat Belt, extending from northern Texas on the south to Manitoba and Sas-

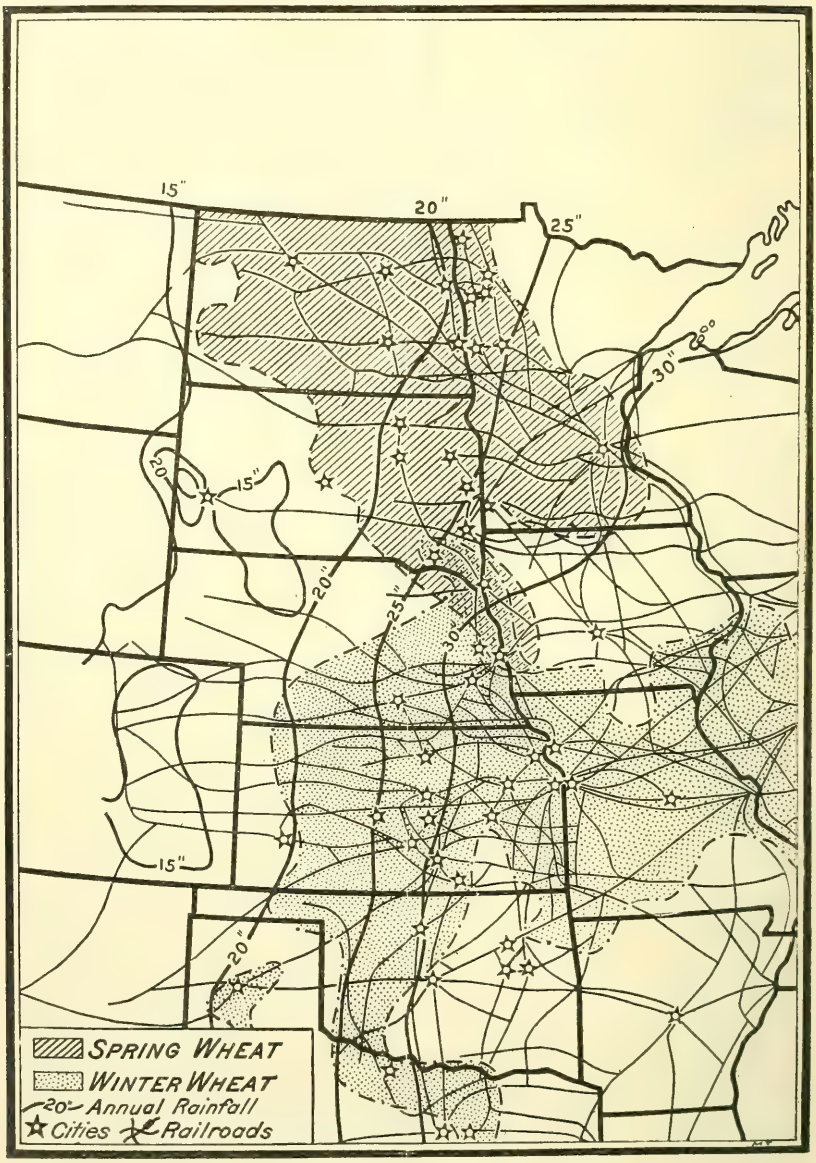

FIG. 1.—The wheat belt of the United States.

katchewan on the north, and, in irregular contour, from the Mississippi River on the east to the arid belt which runs south from eastern Montana to New Mexico. There are two principal wheat-pro-

ducing areas, the winter-wheat area, centering in Kansas, and the spring-wheat area, centering in North Dakota (fig. 1). The wheat areas of Nebraska and South Dakota are much smaller than those of Kansas and North Dakota (Tables 1 and 2).

TABLE 1.—*Wheat production of the United States.*[1]

State.	Average production, 1914–1920.		Percentage of total.	
	Winter.	Spring.	Winter.	Spring.
	Bushels.	*Bushels.*	*Per cent.*	*Per cent.*
United States	587,459,143	246,264,714	100.0	100.0
Total for States given	265,505,143	172,790,285	45.2	70.2
North Dakota	.....	79,737,000	.....	32.4
South Dakota	1,590,000	39,952,000	.1	16.1
Minnesota	1,126,857	47,892,857	.2	19.4
Missouri	38,066,286	266,667	6.5	.1
Nebraska	49,894,000	5,099,143	8.5	2.0
Kansas	116,553,143	423,571	19.8	.2
Oklahoma	40,418,429	.....	6.9	.....
Texas	17,856,429	.....	3.2	.....
All other	321,954,000	73,474,429	54.8	29.8

[1] Figures taken from U. S. Dept. Agr. Yearbooks, 1914–1917, and Crop Reporter, 1918–1920 (revised figures not used for 1919–20).

TABLE 2.—*Average annual production of small grains other than wheat in the Wheat Belt, 1914–1920.*[1]

State.	Average production, 1914–1920 (000 omitted).					Percentage of all small grains.	Percentage of all small grains in wheat.
	Oats.	Barley.	Rye.	Buckwheat.	Total.		
	Bushels.	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*	*Per cent.*	*Per cent.*
United States	1,404,719	206,744	64,257	15,577	1,691,297	66.9	33.1
Total for States given	477,068	101,433	26,876	281	605,658	58.0	42.0
North Dakota	57,689	28,220	9,256	.....	95,165	54.4	45.6
South Dakota	56,720	25,167	4,863	.....	86,750	67.6	32.4
Minnesota	112,724	32,024	6,767	189	151,704	75.2	24.8
Missouri	40,813	185	435	71	41,504	52.0	48.0
Nebraska	77,787	4,756	3,893	21	86,457	61.1	38.9
Kansas	53,454	10,011	1,453	.....	64,918	35.7	64.3
Oklahoma	33,957	772	167	.....	34,896	46.2	53.8
Texas	43,924	298	42	.....	44,264	71.1	28.9
All others	927,651	105,311	37,381	15,296	1,085,639	73.2	26.8

[1] Figures taken from U. S. Dept. Agr. Yearbooks, 1914–1919, and Monthly Crop Reporter, 1920 (figures for 1919–20 not revised).

FLUCTUATIONS IN HARVEST LABOR DEMAND.

Farming is essentially a seasonal industry, and small-grain cultivation is one of the most seasonal forms of farming. At seeding time extra help is needed for preparing the soil and sowing, and in the summer a crew of men for harvesting and thrashing is necessary. During the remainder of the year, however, the farmer and his family, with perhaps a hired man, do the work on the representative grain-belt farm. The harvest labor force is several times as large as the force at work during most of the year. This, essentially, is the cause of the great movement of labor into the southern

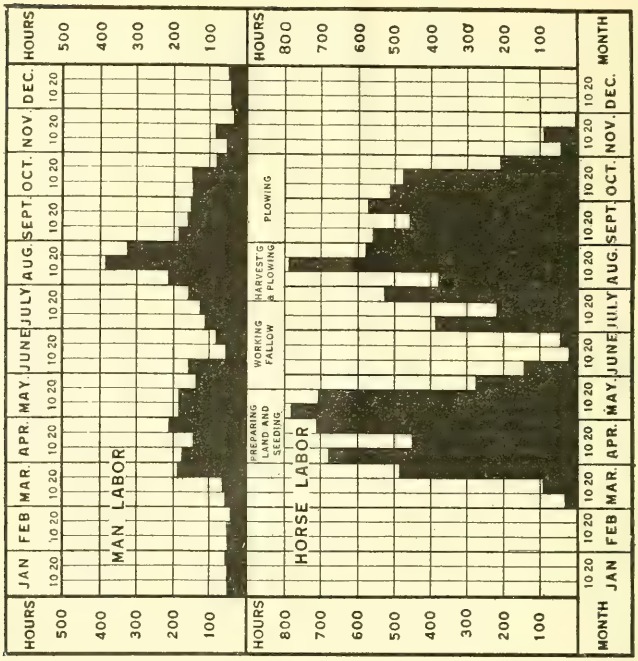

FIG. 3.—Spring-wheat region: Seasonal distribution of total labor on a 600-acre grain farm, North Dakota.[1]

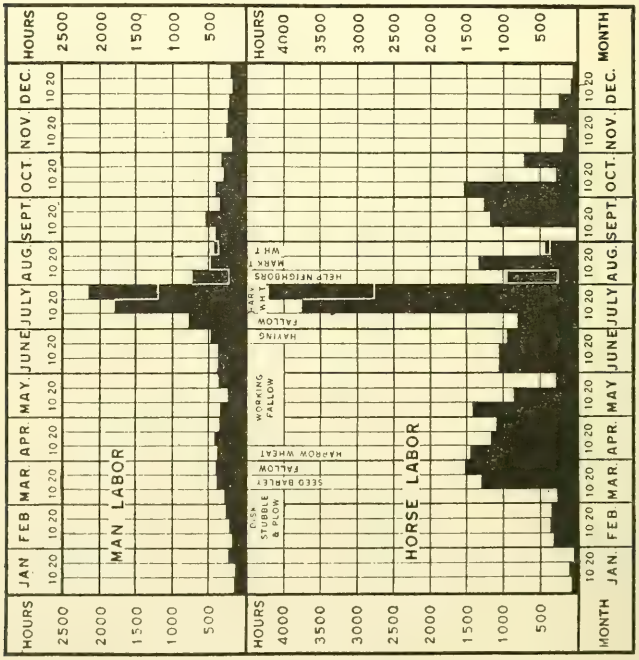

FIG. 2.—Winter-wheat region: Seasonal distribution of total labor on an 800-acre wheat and summer-fallow farm, Walla Walla, Wash.[1]

[1] Reprinted from U. S. Dept. Agr. Yearbook, 1917, Separate 758, "A Graphic Summary of Seasonal Work on Farm Crops," by O. E. Baker, C. F. Brooks, and R. G. Hainsworth.

grain belt in June and July and into the northern area in August and September. Thus an industry which needs only a comparatively small amount of labor during most of the year suddenly requires an army of men to handle its peak load (figs. 2 and 3).

A surprising number of transient laborers secure work of less than a week's duration (Table 4). It was found that on an average men spent 26 days in the harvest area, working 15 days and losing 11 days (Table 4).

TABLE 3.—*Wheat acreage and production in the Wheat Belt, 1918–1920.*

State.	Winter wheat (000 omitted).				Spring wheat (000 omitted).				Percentage production, 1918–1920.	
	Acreage.		Production.		Acreage.		Production.			
	1920	1918–1920 (average).	1920	1918–1920 (average).	1920	1918–1920 (average).	1920	1918–1920 (average.	Winter 1918–1920.	Spring 1918–1920.
	Acres.	*Acres.*	*Bushels.*	*Bushels.*	*Acres.*	*Acres.*	*Bushels.*	*Bushels.*	*Per cent.*	*Per cent.*
Texas	1,225	1,390	15,925	19,555	.....	.....	.....	.....	100.0	.....
Oklahoma	2,890	3,120	46,240	44,393	.....	.....	.....	.....	100.0	.....
Kansas	8,886	9,034	136,844	130,135	17	26	212	246	99.8	0.2
Nebraska	3,335	3,356	58,029	48,835	258	525	2,451	5,228	90.3	9.7
Missouri	2,600	3,361	32,500	48,303	17	23	221	266	99.5	.5
Iowa	431	602	8,491	11,244	400	615	4,520	8,392	57.3	42.7
Minnesota	60	65	1,176	1,131	2,941	3,430	27,940	45,943	2.4	97.6
South Dakota	56	70	812	1,049	2,830	3,227	25,470	38,490	2.7	97.3
North Dakota	.....	.....	.....	.....	7,600	7,790	68,400	76,424	.....	100.0

A few of the men had fairly steady employment. Three farm boys from Ohio, who reached the Oklahoma fields on June 16, obtained 12 days' work in Oklahoma, 35 in Kansas, 10 in Nebraska, and 4 in South Dakota, between June 16 and August 26, when they were looking for thrashing work at Minot, N. Dak. They worked 61 out of 71 days. Allowing for Sundays, in order to compare this work with urban employment, it may be stated that these boys had steady work. Each had sent home about $200, and they had a fair chance for from two to six weeks more without going to Canada. Other fortunate men worked 54 out of 65, 24 out of 27, 18 out of 21, 25 out of 30, 27 out of 36, and 33 out of 41 days. More frequently men worked 12 out of 23 days, 15 out of 37, and 20 out of 36, while those who were most unfortunate worked as little as 10 out of 33, 18 out of 46, 11 out of 37, and ½ out of 11 days. These figures, however, probably are not typical of the average experience of all extra help hired by farmers for the small-grain harvest.

EXPANSION AND CONTRACTION OF ACREAGE.

Ordinarily the harvest opens in Texas and southern Oklahoma between June 1 and June 10 and moves northwest at an irregular rate, depending upon the weather, reaching the Canadian boundary about

the middle of August. The dates when the harvests of the several States begin are shown in figures 4, 5, 6, and 7.

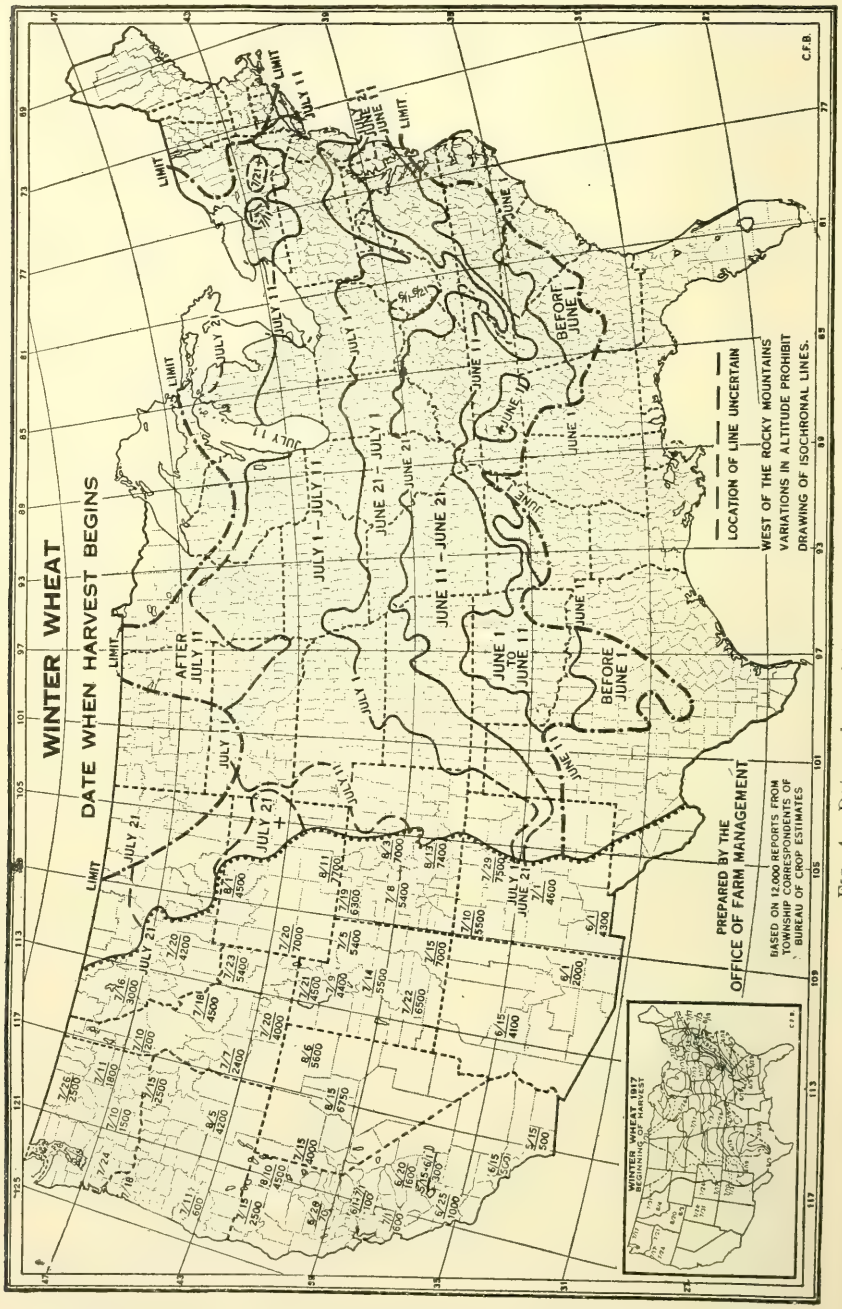

FIG. 4.—Dates when winter-wheat harvest begins.

The Texas and southern Oklahoma acreage, in which the wheat harvest starts, is very small compared with that of north central

Oklahoma and southern Kansas, to which it shifts next (Table 3, and fig. 1.) Opening with a comparatively small demand for labor, most

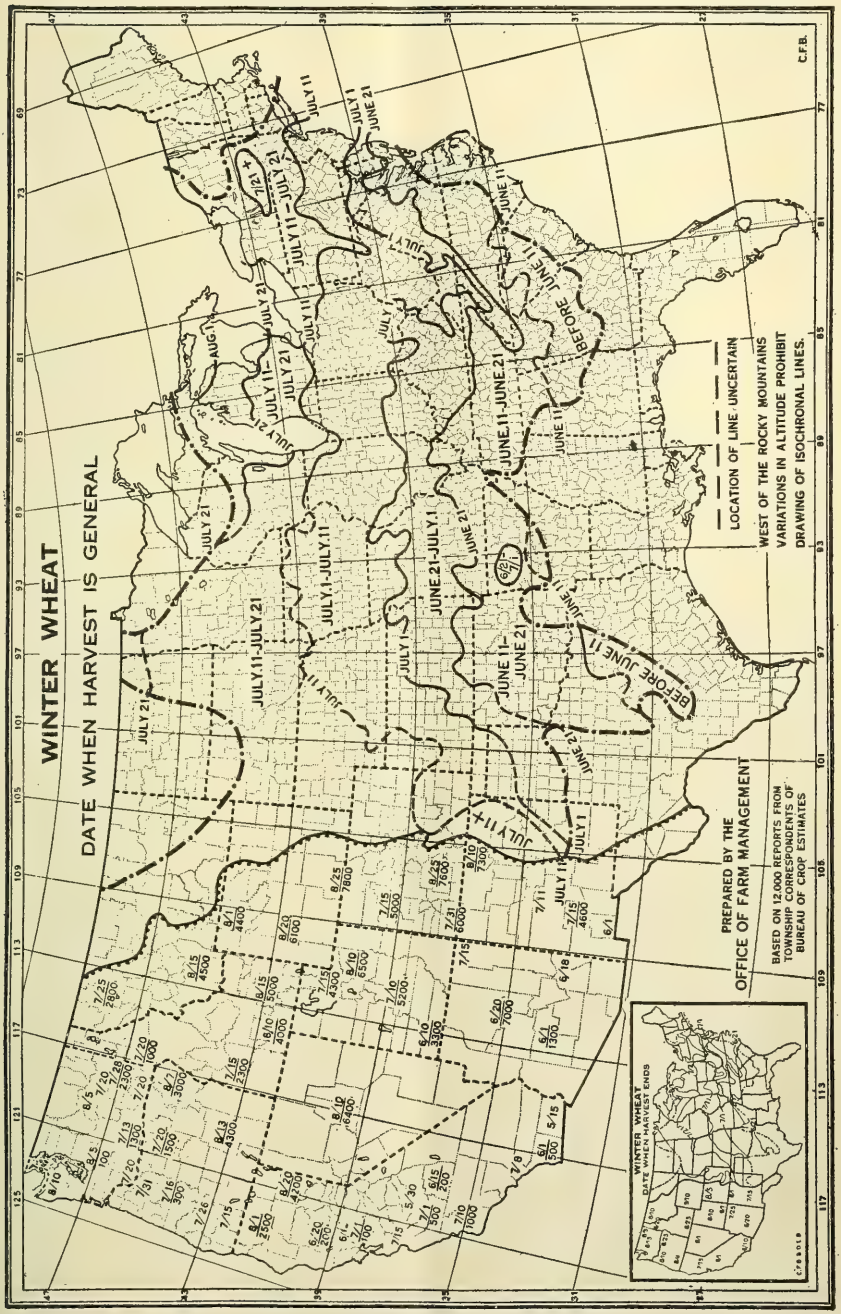

Fig. 5.—Dates when winter-wheat harvest is general.

of which ordinarily is met by residents of Texas and Oklahoma, the harvest creates a rapidly increasing demand for men which reaches

its maximum when the harvests of central and northern Kansas, northwestern Oklahoma, Missouri, and southeastern Nebraska are in

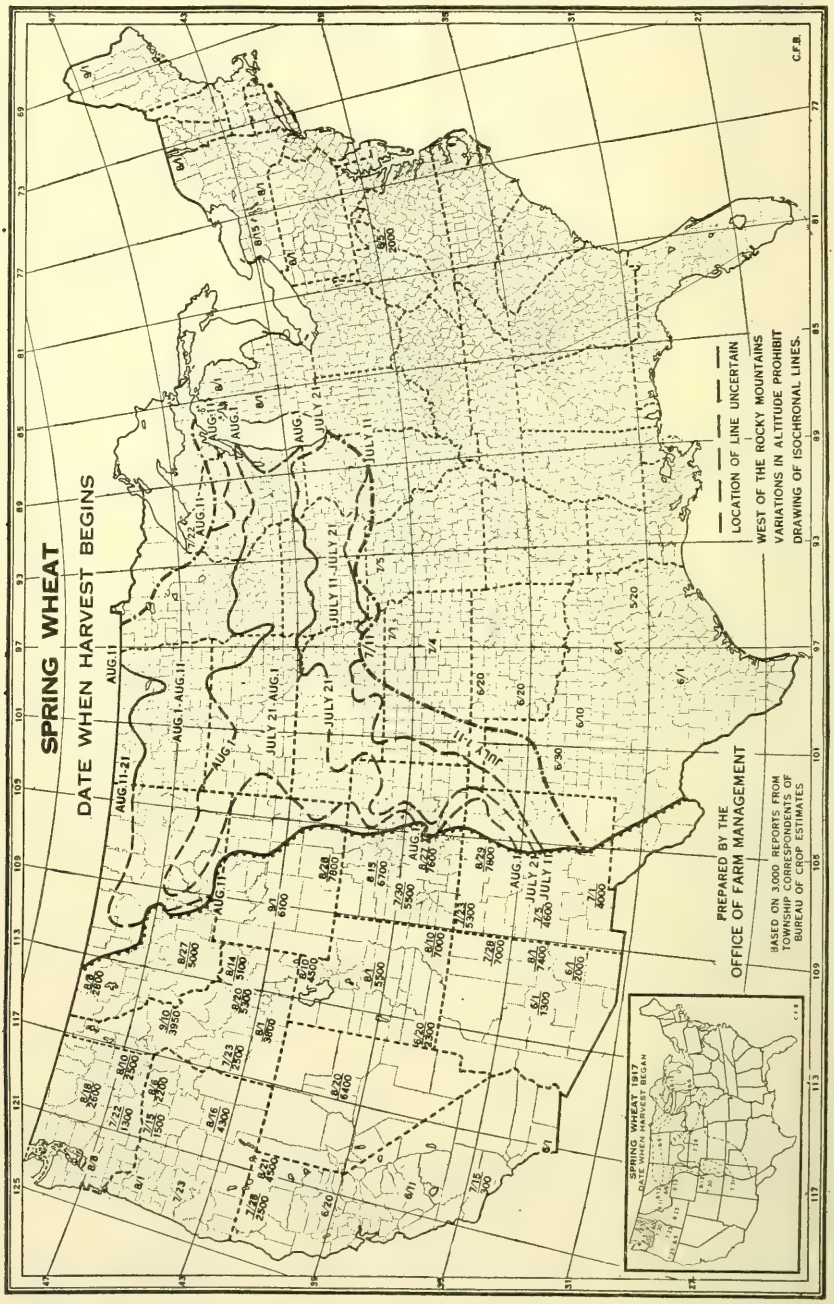

Fig. 6.—Dates when spring-wheat harvest begins.

full swing, from two to four weeks after the grain has been cut in northern Texas. As work in these areas nears completion the de-

mand for labor contracts sharply. The Nebraska, northwestern Iowa, and South Dakota acreage never calls for more than one-fourth as

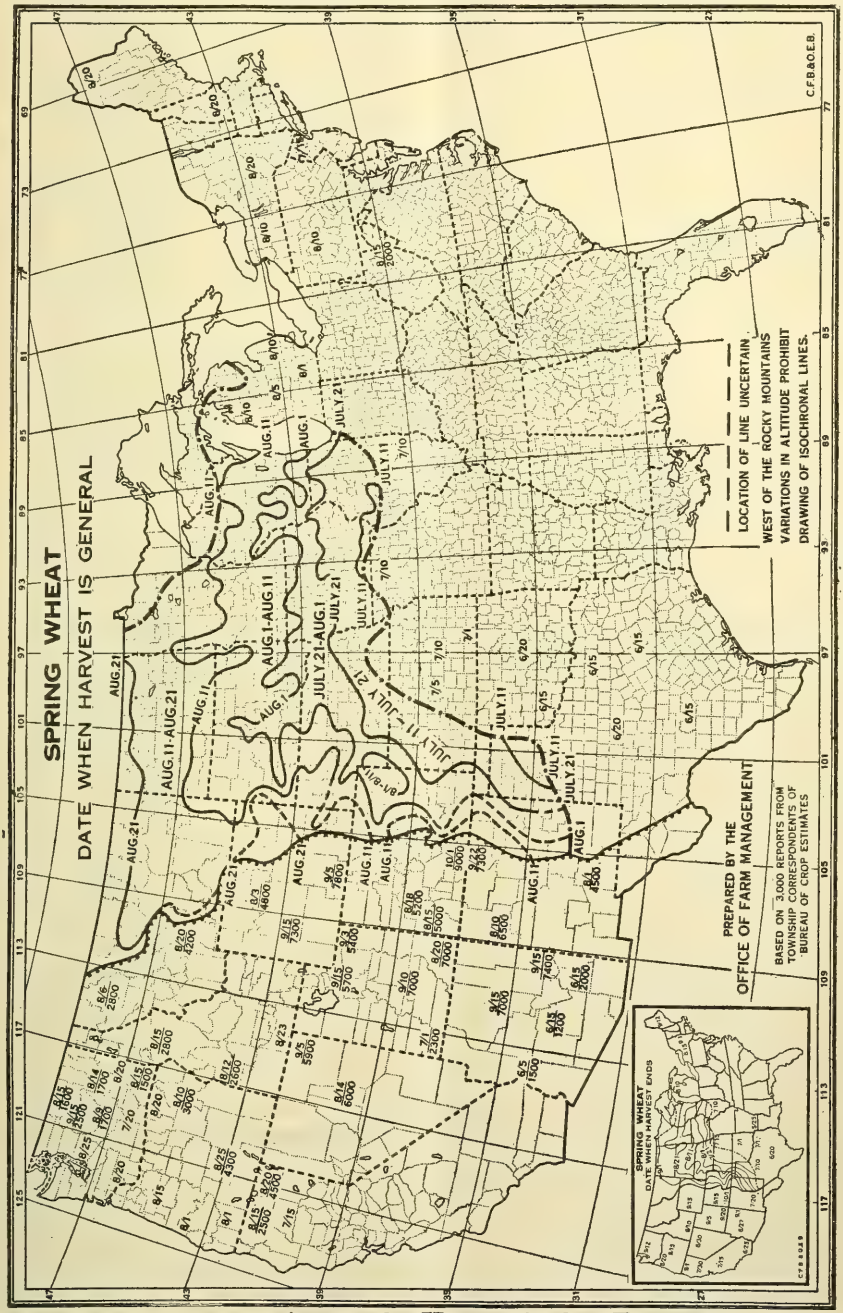

Fig. 7.—Dates when spring-wheat harvest is general,

many men at any one time as the Kansas fields. The acreage statistics (Table 3 and fig. 1) show that a reduction in the labor demand is inevitable during the latter part of July.

TABLE 4.—*Irregularity of employment in harvest (time worked and time lost by 154 harvest hands).*

Regular occupation of 154 harvest laborers.	Total time in harvest area from date of arrival to date interviewed.	Total time worked by each group.	Total time lost by each group.	Time lost by each group.
	Days.	*Days.*	*Days.*	*Per cent.*
Factory hands	443	225	218	49.2
Farm laborers	607	351	256	42.2
Farmers	671	436	235	35.0
Laborers	684	418	266	38.9
Mechanics	647	394	253	39.1
Miscellaneous	202	121	81	40.1
Students	759	392	367	48.4
Average per man	26	15	11	42.3

So far as the demand for labor is concerned, the harvest consists of two distinct but connected episodes. Beginning on a small scale in Texas in early June, the southern (winter-wheat) demand has expanded to a large volume by the last week in June, when Texas, Oklahoma, and southeastern Kansas are at work, and reaches its maximum in Kansas about the middle of July. It then gradually tapers off through the winter-wheat harvest of southeastern Nebraska, shrinking to almost nothing before the end of July. Beginning during the last two weeks of July on the eastern border of Nebraska, the demand for labor for harvesting the spring wheat gradually expands as the harvest goes northward across South Dakota, to reach its maximum by the middle of August in North Dakota, after which it declines rapidly. The largest numbers of men are employed during the first three weeks of August.

If all the harvest hands who work in Kansas should desire to follow the harvest through North Dakota it would be necessary for fully half of them to remain idle for from two to four weeks between the ending of work in Kansas and the beginning of work in North Dakota, and when they reached North Dakota they would be forced into competition for employment with many thousands of men who had come into the northern harvest from the East by way of Fargo and Grand Forks, or from the West, through Montana.

As the Kansas harvest nears completion, the transient harvesters dispose of themselves in various ways. A large number do not attempt to go beyond Kansas, and many experienced workers never have worked outside of the winter-wheat region. Some stay in Kansas through the thrashing season, thousands go home or take up other kinds of work, and others move on to the corn-growing sections of Kansas and of Iowa or return to the cotton region. Another contingent secures employment in Nebraska through employment offices or by going from town to town. As many who have not worked in

Kansas come into the Nebraska harvest about the same time, that State ordinarily has a large supply of men willing to accept wages lower than those paid in Kansas. Another lot of laborers go directly from Kansas to South Dakota, where they are at an advantage in the scramble for harvest work. As a rule, a larger number than can find employment go into South Dakota, soon to be reinforced by thousands from Nebraska, Iowa, and various other States. Some of the Kansas harvesters go into the cities to spend their earnings and later reappear in the northern harvest; others go directly to North Dakota to pick up the early work there. Many leave the harvest entirely.

The total labor contribution of the southern area to the northern harvest can not be computed, but it apparently constitutes a minor fraction of the total harvest labor supply of North Dakota.

CLIMATIC CONDITIONS.

Climatic conditions are the second main factor in the fluctuation of the demand for harvest labor from week to week throughout the season. For instance, in 1920 rain delayed the southern Oklahoma harvest for almost a week. Laborers began to come into the State in late May and early June, until by June 15 a large supply of harvest labor was present. Many men waited so long that their funds became exhausted, while others, growing discouraged, went home before the harvest. On June 29 hot weather called the men to the fields, where the heat soon forced the ripening of the grain as effectively as the wet weather had retarded it. From stagnation the harvest leaped suddenly into extreme activity, so that areas which normally are harvested in succession were ready for cutting at the same time. A dry, clear July enabled the farmers to push the harvest steadily forward, with comparatively little hindrance from the weather, until the middle of August.

In the northern area especially the time of harvest is influenced by the spring weather, which affects sowing and early growing conditions. An early spring in the Dakotas tends to bring the North Dakota and Kansas harvests closer together, a late spring to widen the gap between them.

Oklahoma owes a peculiar labor problem to the climate. The winter-wheat harvest in western Oklahoma and southwestern Kansas (fig. 1) is some two weeks later than that of central Oklahoma and eastern Kansas because of the high altitude and aridity of the western section of these States. Consequently, when the wheat harvest of central and north central Oklahoma is completed the harvesters move north into Kansas,[2] making it necessary for the Woodward district

[2] Topographic maps illustrating this fact are included in U. S. Dept. Agr. Yearbook, 1918, Separate 771, "Arable Lands in the United States," by O. E. Baker and H. M. Strong (Plates II and III).

either to find a new force or get men back from Wichita or Hutchinson when its grain is ready to be cut. Naturally it is difficult to persuade men to return from central Kansas to Oklahoma, as that would make it necessary for them to jump through central Kansas to northern Kansas or Nebraska at the completion of the western Oklahoma harvest. This difficulty is intensified by the fact that ordinarily higher wages are offered in central Kansas than in Oklahoma, and by the lack of good railroad facilities leading into the Woodward district. For the past few years this problem has been met by bringing in students from southern colleges.

EFFECT OF VARIATION IN TIME OF SOWING.

The volume of the demand for labor fluctuates also within each local community because of the irregularity in the time of planting the various fields. As the fields in any neighborhood which are sown on different dates do not ripen at the same time, certain lots of grain are ready to be harvested several days or a week before cutting becomes general, while others may not be ready until most of the neighboring fields have been finished. This condition causes the local demand for labor to open on a small scale, rapidly expand to its maximum, and then taper off to nothing.

One of the beneficial effects of this condition is that some of the men who work in the earliest cuttings later find something to do on other farms, after which they may secure thrashing work in the neighborhood, thus gaining steady employment for from one to three months. At the same time, however, it makes the short period of work the lot of the majority of the hands used in the heat of the harvest. Most of the men who come into a community when the cutting is at its height are forced to leave at the end of from 1 to 10 days.

CROP DAMAGE.

The demand for harvest labor within a State also is apt to be "spotty," because of damage by rust, grasshoppers, drought, hail, and other causes (Table 5) which ruin or materially reduce the crop in some counties. As there is little uniformity in the distribution of these losses from year to year and the harvest hands have no accurate information concerning the condition of the crop in the various localities, laborers frequently go to sections where they found plenty of work during the preceding season, only to learn that crop losses have wiped out the need for them.

This difficulty is augmented by the fact that the crop loss frequently occurs shortly before harvest time. Grasshoppers, rust, heavy storms, etc., need but little time to wreak great damage. For instance, in 1920 serious loss from rust occurred in 20 North Dakota

counties just before the harvest of the late wheat began, while grasshoppers invaded three or four of the northern counties at about the same time.

TABLE 5.—*Cause and extent of annual crop losses of wheat in North Dakota, South Dakota, Kansas, and Oklahoma.*[1]

Year.	North Dakota.				South Dakota.			
	Climatic conditions.		Insects, plant disease, etc.[3]	Total.	Climatic conditions.		Insects, plant disease, etc.[3]	Total.
	Drought, hot winds.	Other.[2]			Drought, hot winds.	Other.[2]		
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1919	30.3	4.3	28.5	63.1	17.8	4.5	30.7	53.0
1918	28.8	7.2	4.1	40.1	3.6	2.9	3.0	9.5
1917	50.0	4.4	1.6	56.0	16.2	4.0	2.8	23.0
1916	9.3	9.2	49.5	68.0	10.3	5.0	38.9	54.2
1915	.8	4.0	6.4	11.2	.1	5.4	6.8	12.3
1914	16.6	6.1	9.5	32.2	26.8	5.6	14.5	46.7
1913	30.4	2.6	3.3	36.3	34.1	1.9	1.9	37.9
1912	3.7	10.5	2.0	16.2	25.3	5.1	4.4	34.8
1911	37.2	6.1	10.9	54.2	67.5	.3	2.2	70.0
1910	62.7	3.0	1.5	67.2	26.9	1.5	2.3	30.7
1909	7.8	7.8	4.0	19.6	7.3	9.9	3.3	20.5
	Kansas.				Oklahoma.			
1919	5.0	18.3	13.6	31.9	1.3	12.7	11.0	25.0
1918	22.9	4.4	1.4	28.7	33.5	4.5	4.3	42.3
1917	27.3	17.3	1.1	45.7	31.0	3.3	1.7	36.0
1916	9.9	13.1	12.1	35.1	20.9	9.6	9.4	39.9
1915	.4	29.9	9.3	39.6	.2	24.8	6.6	31.6
1914	3.0	1.4	3.3	7.7	6.3	2.3	3.7	12.3
1913	25.1	1.2	8.8	35.1	30.7	2.1	7.9	40.7
1912	14.8	9.9	6.7	31.4	19.3	4.6	7.9	31.8
1911	40.5	1.4	3.7	45.6	57.9	1.2	6.7	65.8
1910	18.4	24.7	4.9	48.0	17.1	2.2	3.9	23.2
1909	10.4	14.5	5.2	30.1	21.4	7.3	4.5	33.2

[1] Data furnished by Bureau of Crop Estimates, U. S. Department of Agriculture.
[2] Includes floods, frost, hail, storms, and winter kill.
[3] Includes defective seeds and unknown causes.

CONCENTRATION OF THRASHING DEMAND.

Although farmers may exercise more control over the time of thrashing than over the date of cutting, certain factors, alone or in combination, often give rise to more acute concentration of the labor demand in thrashing than in harvesting.

As the unthrashed bundles represent his year's earnings, the farmer is eager to know how much grain they contain. The farmer in the northern States also fears the coming of bad fall weather before thrashing is finished, and is anxious to get the summer work out of the way so that the fall plowing may be done early enough to permit the weed seeds to sprout before cold weather which kills them. Another important factor is the need for skilled laborers, such as separator and engine men, not required during the harvest. Consequently the demand for thrashing labor is very intense for a short time and then dies away. A large number of men are required for

from two to four weeks to do work which might be handled by a smaller force if it were spread over a longer period. The growing number of farmers who own small thrashing outfits increases the concentration of the thrashing-labor demand and decreases the total length of the thrashing season.

Even in 1920, when there was a plentiful supply of labor during the harvest season, much difficulty was experienced in many parts of North Dakota after August 20 in getting full crews for thrashing. This was caused in part by the marked increase in the number of small thrashing outfits, in part by the fact that hundreds of men in this area were loafing, either because they were holding out for more wages or because they had money in their pockets, and in part by the fact that many of the better class were hastening back to the cities to secure "inside work" for the winter. The Canadian employment service has relieved this situation in the Canadian wheat fields by requiring that some of the farmers wait until the thrashing of the others has been done.

HAPHAZARD DISTRIBUTION OF LABOR SUPPLY.

The harvest hands, coming from everywhere, many guided only by whims, chance, or guesswork, tend to become congested in some places, leaving other localities short of men. Consequently a labor surplus and a labor shortage may exist in the same general section of a State at the same time, and frantic calls for men may come from one town while another near by is wondering how it can get rid of the idle men on its streets. The locality which lacks men naturally reports the fact in the newspapers, which often produces a movement of men from many directions into that section, sometimes continuing until there is an oversupply of labor. Not infrequently the presence of this abundant supply of men tempts some of the farmers to reduce wages, resulting in an exodus which perhaps causes another shortage.

Most of the men attracted to a community for harvesting are let go as soon as the harvest is completed, and move on to other localities. Consequently, when thrashing starts, the wave of men has rolled past, making it necessary to obtain a fresh supply of workmen.

This general lack of system in the distribution of the harvest force over the harvest area, together with the fluctuations in the demand for men, causes much fruitless chasing of jobs, engendering bitter disappointment, and perhaps a sense of injustice.

CHARACTER OF HARVEST LABOR.

The harvest labor force, which never has been and probably never can be counted, but which is believed to include from 150,000 to 200,000 individuals, consists of four groups: (1) Residents of towns of the

small-grain States who hire out to farmers in near-by territory; (2) men who make contracts with farmers from year to year, and know just when and where they can begin the season's work; (3) transient laborers—farmers, mechanics, and others—who leave their regular employment to work temporarily in the harvest fields; (4) transient laborers who are "professionals," in that the harvest is regularly or frequently a part of their year's work.

LOCAL AND CONTRACT HANDS.

Residents of the towns of the small-grain States who hire out to farmers in their own localities constitute a large fraction of the total army of harvest hands. Part of these men follow the harvest northward, but a large proportion remain in their own or neighboring States. Most of them probably either obtain steady work or else return at comparatively small expense to their homes and regular occupations. They are on the spot and in a better position to locate work than those who come to the harvest from a distance. They "know the ropes," and doubtless experience less unemployment than is indicated by the averages in Table 4.

There are also thousands of good men who make contracts with the farmers for whom they work for the following year. A large proportion of these contract hands stay with the farmers hiring them for the harvest through the thrashing and even for corn picking, fall plowing, and other work. Although some follow the harvest north after finishing their first piece of work, others accept steady employment in the same neighborhood.

Several farmers near Ellendale, N. Dak., stated that they had made advance contracts with the same men for a number of years. Moreover, three of the most successful farmers in that community had come there originally as migratory farm laborers, made advance contracts for the following harvest, then contracted in advance for the whole crop season, and finally had put a season's earnings into horses and equipment, rented land, and taken up farming for themselves. One of these men had more than 400 acres of wheat in 1920.

Working for from 45 to 100 days, sometimes more, at high daily wages and spared the expensive railroad fares and hotel bills which fall to the lot of the migratory harvest hand, the local and contract laborers are the ones who really "make a stake" in the harvest.

TRANSIENT HANDS.

The transient harvest hands fall into two groups: (1) Farmers, mechanics, and farm and other laborers who have left their regular occupations temporarily to make the harvest; and (2) the seasonal laborers, to whom the harvest is a regular or important part of the

year's work. Both of these groups are forced to seek employment wherever it can be found in the harvest States and to move from place to place, filling the farmers' needs for extra help. In other words, the transient workers constitute the short-time help which the farmer hires to carry his "peak load," while the local and contract groups get the bulk of the steadier harvest jobs.

The place of residence of 2,407 transient harvesters was investigated. Some of the men interviewed said that they had none, which was literally true. The following summary shows the States from which the greater proportions of these harvesters came:

Missouri	421	Oklahoma	80
Illinois	251	Arkansas	79
Ohio	173	Wisconsin	73
Iowa	180	New York	66
Kansas	143	Pennsylvania	66
Indiana	129	Texas	64
Total	1,297	Total	428
Fifty-four per cent of total.		Eighteen per cent of total.	

These 12 States contributed two-thirds of the transient harvesters. Of the first 400 men placed in the harvest by the Sioux City employment office, 307 came from the Missouri group of States, Minnesota and Nebraska. The rest of the 2,407 men came from every State in the Union, a few from each State. Forty-three were foreign born. During the 1919 harvest the Kansas City office of the United States Employment Service recorded the places of residence of 14,613 men sent into the harvest fields. The figures show that 8,787, or 56 per cent, came from Missouri, Illinois, Iowa, Ohio, and Kansas, which States contributed 1,052 of the 2,407 men interviewed in 1920. While the 14,613 men included some from every State in the Union, 84 per cent came from 16 States in the Middle West, and only 16 per cent from the remaining 32 States.

Is it true that 50 per cent of the transient harvest force come from Missouri, Illinois, Iowa, Ohio, and Kansas? The figures show that although these States contribute large contingents to the harvest field, they do not contribute a correspondingly large percentage of the total force. The data for 1920 were gathered for the most part from harvesters who visited the United States employment offices at Kansas City, Mo., Colby, Pratt, Wichita, and Salina, Kans., and Sioux City, Iowa. Some of the interviews occurred in Aberdeen and Redfield, S. Dak., and in Fargo and other cities in North Dakota. As the figures for 1919 were compiled at Kansas City, Mo., the men interviewed were almost entirely those who entered the harvest fields from the East and South. Kansas City, Sioux City, and Fargo are gateways from the East into the harvest fields. The men of Ohio,

Illinois, Indiana, New York, and Pennsylvania either pass through Chicago or go by way of St. Louis or Omaha to Kansas City, Sioux City, Sioux Falls, or other cities in the eastern section of the small-grain area. The Wabash; Chicago, Milwaukee & St. Paul; Chicago & North Western; Rock Island; Great Western, and other roads constitute direct feeders from the East into the harvest fields. Thus a great many of the harvest hands encountered in the cities which are the eastern gateways of the harvest come from the territory to the east. On the other hand, many Oklahomans and Texans go into Kansas City to find work in Kansas and Nebraska after they have finished their labors in the southern territory. It is not strange, therefore, that only 26 of the 2,407 men in 1920, and 67 of the 14,613 men in 1919 came from California, and that of the 2,407 men only 9 came from Wyoming, 5 from Washington, and 3 from Oregon.

MOTIVES.

The motives which bring the harvest hand to the wheat fields are as varied as human life. This investigation showed the presence in the fields of farmers whose crops had been ruined or impaired by hail, drought, storm, or fire; some who had not enough land under cultivation to afford them a livelihood, and others who were seeking new locations; students and young men who were looking for experience, a vacation, a chance to see the world; prodigal sons trying to earn enough money to return to the homes they had forsaken; soldiers and sailors who had developed a thirst for roaming while in the Army and Navy; and men attracted by the lure of the great out-of-doors or the pleasure of harvesting.

The desire for adventure and experience brings thousands. The grain harvest of the Central West is one of the few big adventures left in American life. The frontier and the Indians have been conquered; the lands of the West have been put under the plow; the secret resting places of the gold and silver have been explored and exploited; and the harvest mobilization now remains the most dramatic, adventurous experience in the industrial life of the Nation. From every State in the Union men of a hundred different occupations come to rub elbows for a few days or weeks in the garnering of millions of bushels of grain over a territory adequate for an empire, and then vanish one by one back into the everyday walks of life. The quiet pursuits of agriculture become dramatic; imaginations are fired; the glamour and lure of adventure prevail over the humdrum of life.

The fascination which harvesting itself has always had for the human race is another attractive force. Men enjoy garnering na-

ture's products, and the gathering together of groups of workers to care for the harvest has always been one of the joyful experiences of the race. The mere pleasure of participation with hundreds of thousands of others in harvesting millions of bushels of grain is a strong incentive.

Asked why he has come to the harvest, the seasoned "floater" probably will answer that "the harvest is a habit," that he swears each year he will never come again, but can not seem to resist when the time comes. It fascinates him with its multitudes, its unknown possibilities, its chance that "something may turn up."

The hope of large earnings and the lure of adventure attract men to the harvest; *unemployment drives them.* A large number of factory hands, particularly from automobile and tire factories, came to the harvest of 1920 because they were out of work. The chance to make money in the harvest came just when they lost their employment. This, of course, is true of many harvesters every year, and it was because other industries were busy that a serious shortage of harvest labor was feared in 1918 and 1919.

Of the thousand and one incentives which lead tens of thousands of men to take part each year in the small-grain harvest, these three stand out most prominently: (1) Lack of other employment, either permanent or temporary; (2) the hope of making "big money"; and (3) the desire for adventure and experience. In addition, many thousands of seasonal workers flock to the wheat fields as part of the year's cycle of employment.

CHARACTERISTICS.

Fairly complete autobiographies were obtained from 153 harvest hands who came to the public employment offices in Kansas City, Sioux City, Aberdeen, and Fargo (Tables 6 and 7).

TABLE 6.—*Age of becoming wage earners, education, and occupational training of 153 transient harvest hands.*

Age of becoming wage earners.	Number of cases.	Education.	Number of cases.	Occupational training.	Number of cases.
Years.					
Under 14	26	None	2	Raised on farm	94
14	29	Less than fifth grade	11	Trade apprenticeship	7
15	30	Fifth to eighth grade	103	None	52
16	24	Ninth or tenth grade	13		
Over 16 years	33	Finished high school	5		
In school	11	Commercial college	2		
		In college	11		
		Unknown	6		

TABLE 7.—*Age of 919 harvest laborers.*[1]

Age group.	Group 1.[2]		Group 2.[3]		Group 3.[4]		Total.[5]	
	Number.	Per cent.	Number.	Per cent.	Number.	Per cent.	Number.	Per cent.
Years.								
Under 20	5	3.3	22	9.2	62	11.8	89	9.7
20–24	25	16.3	93	39.1	169	32.0	287	31.2
25–29	21	13.7	43	18.1	117	22.2	181	19.7
30–34	17	11.1	33	13.9	60	11.2	110	12.0
35–39	30	19.6	11	4.6	55	10.4	96	10.4
40–44	15	9.8	15	6.3	17	3.3	47	5.1
45–49	19	12.4	9	3.8	24	4.6	52	5.7
50–59	18	11.7	7	2.9	20	3.8	45	4.9
60–69	1	.7	4	1.7	4	.7	9	1.0
70–79	1	.7	1	.4	------	------	3	.3
83	1	.7	------	------	------	------		

[1] All of the 919 men whose ages are presented in this table were interviewed during the harvest of 1920.
[2] Consists of 153 men from whom life histories were obtained.
[3] Consists of migratory laborers.
[4] Consists of 528 applicants for harvest work at various public employment offices.
[5] Representative index of the ages of harvest laborers.

Of these 153 men 13 were farmers, most of whom owned small farms or partially-developed homesteads, who were "making the harvest" to obtain cash to develop their farms or to eke out the meager incomes from their lands; 20 were mechanics, factory hands, or members of some other mercantile occupation, for the most part temporarily unemployed; 11 were college or high-school students out to earn money to complete their education. A father and son, traveling by automobile in search of a permanent location, were working in the harvest to replenish their purses. A young man who owned part of a transfer business was after cash to put into the venture. The owner of a half interest in a thrashing outfit and sawmill in Saskatchewan makes the harvest each season as a regular part of his year's work. An ex-United States marine, 29 years old and with no civil occupation, was taking a final fling at civil employment before reenlisting.

To many men of this type the harvest offers an opportunity for self-advancement. Farmers with insufficient capital or those whose farms can not provide an adequate income are helped through the critical period in their farming operations by their harvest earnings. Some in time will become successful farmers; others always will need to eke out their regular incomes. Students receive assistance through college; young men in business add to their working capital; and mechanics and factory hands meet the emergency of temporary unemployment.

Agricultural and employment officials in the southern wheat area frequently commented upon the increasing number of college men making the wheat harvest. The county agent at Enid stated that

90 per cent of his preharvest correspondence with harvest hands had been with college men. Three hundred college men were sent in one group into the Woodward district in Oklahoma and over 800 were placed by the State employment service. Between one-third and one-half of the harvest placements of the Enid office were college men. In the opinion of the labor officials and county agents, the presence of these men had raised the tone of the harvest work materially in the areas affected.

To the majority of the harvest army the harvest means sustenance. Of the 153 men interviewed 103 were of this type. Forty-eight had regular occupations and either spliced harvest or other seasonal work into periods of unemployment or came to the harvest because they could thereby increase their annual incomes. For instance, one who worked regularly in a brickyard was forced to seek other employment during the war. When the brickyard resumed operations he returned to it. Another fed cattle for the market for stockmen, and made the harvest largely for his health. A third worked in steel mills, coming to the harvest because work in his regular craft was slack. Many others were farm hands who hire out by the month on farms, changing farms more or less frequently, and who had left their places permanently or temporarily in the hope of making more money. The other 55 of the 153 men interviewed were confirmed migratory laborers. To use their own expression, they were "on the road"; to use the designation common in the wheat area, they were "floaters." The "floater" is a rover, who seldom works very long on any job, having for his goal a "stake" to tide him over the winter or furnish him with a good time. His preference is for work where board and lodging are furnished by the employer.

Every one of the 153 started life in an humble home; 94 on farms and the others in cities or villages. Sixty-two of the 103 migratory laborers were born and raised on farms. Less than a dozen of the 153 came from homes that might be called comfortable. Seventeen found their first employment in factories, 10 in grocery stores, 6 as office boys, 3 in mines, and 94 on farms.

Twenty-nine of the 153 were born in foreign countries. The majority of these men grew up on farms, although a few came from cities and 2 from the families of sailors. Thirty-nine of the 124 who were born in the United States came from the wheat belt States, 56 from States surrounding the wheat belt, and 16 from eastern and Pacific Coast States. The remainder said simply that they were "American born."

The regular occupations of three groups of transient harvest hands are given in Table 8.

TABLE 8.—*Regular occupation of transient harvest hands.*

Occupation.	Group 1.[1]		Group 2.[2]		Group 3.[3]	
	Number.	Per cent.	Number.	Per cent.	Number	Per cent.
Farmers and farm laborers	844	30.6	186	46.5	5,360	36.7
Laborers, city and floating	785	28.5	51	12.8	4,409	30.2
Factory operators	173	6.3	24	6.0	8	(4)
Mechanics	432	15.7	71	17.8	2,192	15.0
Students	242	8.8	40	10.0	818	5.6
Chauffeurs	63	2.3				
Office help	57	2.1	11	2.8	435	3.0
Bookkeepers, etc	14	(4)				
Teamsters	40	1.5	2	(4)		
Miners	37	1.3			379	2.6
Linemen	13	(4)				
Teachers and professional men	24	(4)	4			
Railroad men	11	(4)	2		341	2.3
Government employees	8	(4)	3			
Contractors	6	(4)				
Sailors	3	(4)				
Business men	2	(4)			190	1.3
Others			6		481	

[1] 2,754 harvesters interviewed in 1920, in Oklahoma, Kansas, North Dakota, and South Dakota.
[2] First 400 harvesters placed by Sioux City employment office, in 1920.
[3] 14,613 men placed by Kansas City, Mo., employment office, in 1919.
[4] Less than 1 per cent.

Some of the 153 harvest hands interviewed had acquired property, but the majority had not. Nineteen had bought farms and 12 had homesteaded farms, while 17 had rented farms. Four of those who had bought land never farmed it, and 13 were farming at the time. Most of the remaining 31 who had tried farming had made a failure of it. Although some admitted that they lacked ability, most of them attributed their failure to drought. Whatever the reason, the fact remains that 27 of the 43 men who attempted farming were unsuccessful and that 12 others came so close to failure that they were piecing out their farm incomes with harvesting. Of course, this situation is not always the fault of the farmer. Two Montana farmers interviewed had been "hailed out," one three years in succession, making it necessary for them to come to the harvest to support their families through the winter.

Fifty-nine, including the 31 who owned farm land, stated that they owned real estate, Government bonds, or cash. The ages of 21 men whose entire savings were less than $500, ranged from 35 to 70 years. These 21 men had simply "a little nest egg against a rainy day," as one of them expressed it. Three others were worth more than $500 but less than $1,000; seven had from $1,000 to $1,800; four from $2,000 to $3,000; one had a house and lot and $2,000; one had $5,000; one, $7,100; one, a dairyman, $10,000; one, a section of land, $4,000 worth of farm equipment, and $4,000 in cash; one a flat building in Chicago worth $35,000; and another some Pennsylvania coal lands and urban property worth $43,000. The other 16 owned real estate of uncertain value. Eighteen of the men who claimed that they had saved some-

thing were "floaters," whose savings averaged $345. The only one of them possessing more than $500 had put $1,500 of his earnings in a bank years ago. Three had less than $100. In contrast with the "floaters," 11 farm hands reported average savings of $4,475 each, and 3 others owned farms or urban property.

Only three had made an outstanding financial success as a result of their knowledge of farming, and none was an operating farmer. One had been a foreman on one of the largest wheat farms in North Dakota for seven years, leaving it to operate a farm in Saskatchewan, which he later left to enlist in the Canadian Engineers. He is worth over $10,000. The second, skilled in handling purebred cattle, had been able to earn more than the "going wages" and had saved over $10,000. Although he had worked for 22 years on farms, he never had operated one for himself. The third, raised on a farm, had acquired a comfortable fortune by trading in real estate. Eleven other farm hands had accumulated sums three or four times as large as the savings of the industrial laborers.

Very few criticized the farmers as employers. Nearly all of the men said that the farmers had generally "treated them square." Many of the older men qualified this statement by saying that they "treat labor better than they used to do." The men were practically unanimous in saying that they were well fed. Complaints against sleeping quarters were more frequent.

MOBILIZATION OF HARVEST LABOR.

The outstanding labor problem of the wheat harvest is the mobilization of an adequate but not excessive supply, followed by a proper distribution of the workers over the harvest areas, not only once, but again and again. This problem consists, on the one hand, of dividing the available force in an equitable manner so that each wheat farmer may have the number of men that he needs, and, on the other hand, of helping each harvester to work as steadily as possible with a minimum expense of travel and board. The number of men needed varies year by year with the acreage planted to wheat, the condition of the crop, the length of the straw, and the amount of unemployment in the cities and towns in or near the wheat belt.

FORECASTING THE NUMBER OF HARVEST HANDS NEEDED.

Prior to the opening of the harvest many attempts are made to forecast the number of harvest hands that will be needed from outside the wheat States. Some of these estimates are wild guesses, based upon no definite knowledge of the amount of labor needed in the various portions of the wheat area or of the number of harvest hands who move northward, supplying labor to one section after another. The only

known definite formula for computing probable harvest demands was evolved at a conference of county agents at Manhattan, Kans., in November, 1919, and later used in Kansas. This formula gives a reasonably conservative estimate of the amount of labor needed. The office of Farm Management and Farm Economics had found that the average header crew consists of 6 men; the county agents of Kansas had found that a county is usually harvested in about 10 days; and it was found that a crew harvests, on the average, 30 acres a day. Assuming a supply of labor on the farm averaging 1.3 men to a farm, the following formula was devised:

Divide the number of acres of wheat in the county by 50, subtract the man power on the farms and that available from towns within the county. The difference represents the men needed from outside the county. This formula may be expressed as follows:

A = number of acres of wheat within a county.

mf = man power of the farms (number of farms multiplied by 1.3).

mt = man power available from towns within the county.

mo = number of men needed from the outside.

$$\frac{A}{50} - (mf + mt) = mo.$$

While this formula would not apply accurately to counties that do not use the headers, it is better than wild estimates for computing the demand in any wheat county.

Applying this formula to the 8,943,000 acres of wheat harvested in Kansas in 1920, the State farm demonstrator estimated a need for 50,000 men in addition to those resident in the wheat counties. If this figure be correct, Texas and Oklahoma probably needed from 20,000 to 30,000 men, at least half of whom would go north into Kansas, while the Nebraska and South Dakota demand would not exceed half of the Kansas demand.

North Dakota's demand might require as many outside men as that of Kansas, as there is more shocking in North Dakota and the State is less densely populated than Kansas. John Hagen, commissioner of agriculture and labor of North Dakota, estimated a need for but from 15,000 to 20,000 men for August in North Dakota in 1920,[3] apparently a conservative estimate, but lacking the accuracy of the Kansas method. Forty-two North Dakota farms, with a total acreage of 56,908 acres, 20,642 acres of which were in small grain, employed 164 men, or one man for each 125 acres of small grain. On this basis the 12,279,000 acres of wheat, oats, barley, and rye in North Dakota in 1920 required a labor force of 98,000 men, in addition to the families and regular hands on the farms. It must

[3] Hutchinson (N. Dak.) Tribune, July 20, 1920.

be remembered, however, that many transient harvest hands, probably at least two-thirds of them, work on several different farms, so that 25,000 or 30,000 men no doubt can take care of the North Dakota work. On the other hand, men are leaving the harvest fields every day of the season, making it necessary for new men to take their places.

While it probably is correct to state that from 100,000 to 200,000 individuals find employment in the harvest, there is no basis for saying that the demand for harvest labor reaches such large figures on any one day. On the other hand, thousands of harvest hands remain to thrash where they have harvested, and the contemporaneous demands of thrashing and harvesting increase the total demand for labor during the last four or six weeks of the harvest far beyond the harvest demand proper. Thousands of the men who take part in the harvest in Oklahoma, Kansas, and Missouri do not need to go into the northern harvest, as they can find plenty of work thrashing and cultivating corn in the winter-wheat area. Ordinarily, however, their places are more than filled by the thousands who enter the northern harvest without having worked previously in Kansas.

MOBILIZATION MACHINERY.

Unquestionably the newspapers are the most important means by which men are attracted to the harvest. They begin in May and early June to publish statements of the prospective labor needs and wage scales in the harvest area. Active advertising of harvest work by employment agencies, public and private, also stimulates the flow of men toward the grain fields. A third important influence which arouses interest in the harvest in the minds of workmen is conversation with men who have been to the harvest. More than a million individual wage earners in the United States have "made the harvest" one year or another, and many of them have found their experience satisfactory. Scattered through the various industries, on farms, in railroad and construction work, or in factories, these men tell their companions about the harvest, often enlisting a "buddy" to return with them. The harvest furnishes the theme for many an animated discussion in the shanties of the lumber camp, in the Chicago, Omaha, or Minneapolis lodging house, during the factory lunch hour, or in the pool room. No one can foretell how many men this sort of advertising will bring in any given year, whence they will come, or when they will arrive. But each season it recruits thousands. The railroads running through the grain belt gather estimates of the crop conditions and prospective labor demand in each locality from their local agents in that area, and are thus able to make a reasonably accurate advance approximation of

the demand along their lines, although they are unable to tell exactly how many men are needed and the extent to which the demand has been filled at any given time or the agencies which are working to satisfy the demand.

Most of the men interviewed said that they had received the information which prompted them to come to the harvest through conversations with friends, acquaintances, or fellow workmen or through the newspapers. Those who previously had been in the harvest relied upon their own experience, supplemented by information which they obtained from newspapers, and occasionally from local United States employment offices. Those who had not been to the harvest before depended chiefly upon what friends told them. Many of the college students had written to United States employment offices in the harvest area for detailed information. The migratory laborer talks indefatigably, and the rapidity with which industrial information spreads among this class by word of mouth is astonishing. Like the greenhorn, the floating laborer depends largely upon hearsay for guidance as he goes to the harvest, but he is able to test the value of the statements of others by comparing them with his past experiences. The more intelligent among them, moreover, seem to discount the statements which other workmen make, and feel safe in drawing conclusions only after they have talked with many men.

Harvest hands often complain that much of the information to which they have access is not dependable. Newspapers frequently are misinformed, and sometimes do not possess all the facts bearing on the situation. It is particularly easy for papers distant from the wheat belt to accept distorted statements of the harvest situation.

A. L. Barkman, zone clearance officer of the United States Employment Service at Kansas City, in discussing this type of advertising in his annual report, dated August 10, 1920, says:

> This year, unfortunately, a great many men were induced to enter the fields two weeks too early by independent and wildcat advertising on the part of persons who were more concerned in securing a surplus of labor than in an equitable distribution and a square deal to the men. Independent advertising is hard to control and men who are induced to go to the wheat fields by inspired news stories, paid advertising, etc., unless such advertising bears the indorsement of the Employment Service, always take a chance of being the victims of selfish communities or individuals.

J. H. Crawford, Federal State director of the employment offices of Kansas, called attention to the same evil in his annual report for 1920:

> A number of erroneous articles were published in the daily papers and several localities issued handbills several weeks in advance of the harvest, and this brought men into the field too soon, some not being prepared financially to maintain themselves away from home. * * * This advance publicity is a matter, of course, we were unable to control, on account of it coming from so

many sources. We were very careful, at all times, in giving articles to the press, to give only the exact conditions.

To be reliable, advertising must be centralized and coordinated. To give out accurate forecasts of the need for harvest labor, all agencies need information upon the acreage to be harvested, the condition of the crops in each locality, the available local labor supplies, weather conditions, the agencies which feed labor into the harvest, the experience of preceding years, the unemployment that prevails in the cities of the central part of the country and the wages current there, and the extent to which the labor employed in the southern wheat area can be used in the northern area. Only a Government office in touch with responsible correspondents throughout the wheat belt and able to combine and analyze their reports is in a position to appraise correctly the harvest labor needs or to forecast harvest wages.

Prior to 1917 little had been done to provide authoritative information about the harvest for prospective laborers and for the guidance of employment agencies. Meetings of State employment officials had been held at Kansas City in 1915 and 1916, but not much more than the exchange of information and the creation of personal contacts among the officers of the several States was accomplished. As a result of the activities of the Federal Department of Labor, begun in 1917, 49,000 posters announcing the labor needs of the wheat belt were sent to as many post offices in 1918 and 1919, resulting in inquiries from over 20,000 individuals. Later, 17,000 posters announcing the location of wheat-belt employment offices were put up in the States from which the bulk of the harvest hands were expected. Of the 93,000 men who came to these offices 46,242 were definitely placed.

During the winter-wheat harvest daily bulletins are issued by the Employment Service, in cooperation with the farm management demonstrator of Kansas, but this bulletin service has not yet been established in the spring-wheat area. These bulletins give specific, up-to-the-minute information on the demand and supply of labor, wages, weather conditions, and the stage of the harvest, to the harvest hands, farmers, employment offices, county agents, and newspapers. They prevent much of the aimless wandering of men in search of work which results in oversupply at one point, while grain is being shattered and lost at other places because of a lack of men.

DISTRIBUTION OF HARVEST LABOR.

DISTRIBUTION MACHINERY.

The information service already described is an important means of harvest-labor distribution. A large proportion of the harvest

hands do not attempt to secure information at the employment offices, but go out into the small towns, where they are picked up on the streets by farmers. If they do not find work in one town they go on to another. Daily bulletins which tell where men are needed and what communities already have enough labor enable them to go where there is some chance for work rather than where there are too many men. Of course, as long as men wander from town to town, guided only by general information, contemporaneous shortages and surpluses of labor will exist.

Sometimes the scattering of the labor force through the small towns in advance of specific orders from farmers benefits both the men and the employers. During the early part of June, 1920, when rainy weather delayed cutting, thousands of men left such distribution centers as Kansas City and Wichita and went out into the small towns in the heart of the wheat belt. When the rainy weather was succeeded by a sudden hot wave the men were ready to step into the fields in many parts of the wheat area. Under ordinary circumstances, however, the most efficient distribution of the labor is attained when the farmers place their orders with local representatives of the Employment Service and the men go directly from the employment offices to the localities where they are needed.

The organized machinery of labor distribution in the wheat belt consists of State and Federal employment services working in cooperation. The United States Employment Service, having its central office at Kansas City, has endeavored, with marked success, to coordinate, centralize, and make effective all public employment agencies in the grain belt, and to establish complete cooperation with the representatives of the United States Department of Agriculture and State and local agricultural officials. The United States Department of Agriculture has furnished the employment services with crop information, and the county agricultural agents and farm bureaus have assisted in placing harvest hands on farms.

Several of the States in the grain belt have State employment offices. Oklahoma has two, one at Enid and one at Oklahoma City; Kansas, six, at Topeka, Kansas City, Parsons, Wichita, Salina, and Hutchinson, with the Kansas City, Mo., office for all practical purposes a part of its system; and Nebraska three, one at Omaha, one at Lincoln, and one at Fairbury. Sioux City, Iowa, is the basic distribution point for harvest labor for Nebraska and South Dakota, while South Dakota has offices at Sioux Falls and Mitchell, and North Dakota one at Fargo.

As the permanent offices are too few to meet the needs of the harvest situation, temporary offices have been established in each of the last three years for the harvest period. Some of these have been financed from Federal funds, others from State funds, and many

from Federal and State funds combined. Such temporary offices were established in 1919 in Oklahoma at Alva, Carmen, Kingfisher, Woodward, and Guymon; in Kansas at Liberal, Goodland, and Dodge City; in South Dakota at Aberdeen, Redfield, and Watertown; in North Dakota at Oakes, Jamestown, and Grand Forks. In 1920 temporary offices were maintained at most of these towns, as well as in Bismarck and Minot, N. Dak., and Fort Worth and Amarillo, Tex. Extra clerks also have been added to the more important permanent offices, such as Kansas City, Wichita, Salina, Hutchinson, Sioux City, and Fargo, during the harvest.

These Federal and State employment offices, however, are merely central distributing points for harvest labor, and must be supplemented by local distributing agencies in each county. The county agricultural agents, farm bureaus, local chambers of commerce, local bankers or business men, and other organizations or individuals have been made local representatives of the various employment offices. These local representatives receive the orders of the individual farmers for men and telephone or mail them to the labor distributing points. The men are then sent to the local representatives, who place them on the individual farms. Relatively few men are sent directly from the employment offices to the farmer.

One of the most serious needs of the labor-distribution organization in the wheat belt is the establishment of a large, well-equipped office at Kansas City, Mo.

TRANSPORTATION OF HARVEST LABOR.

The expenses of the large number of harvest hands who come long distances to the harvest are heavy before they begin work. (Table 9.)

TABLE 9.—*Expenses incurred by 2,643 transient harvest hands, before beginning work in the harvest.*[1]

Expense.	Number of cases.	Percentage of cases.
Less than $10	663	25.1
$10 to $14.99	248	9.4
$15 to $19.99	424	16.0
$20 to $24.99	324	12.3
$25 to $29.99	228	8.6
$30 to $34.99	164	6.2
$35 to $39.99	92	3.5
$40 to $44.99	117	4.4
$45 to $49.99	38	1.4
$50 to $59.99	316	12.0
$60 to $69.99	18	.7
$70 to $79.99	2	.....
$80 to $89.99	1	.....
$90 to $99.99	5	.....
$100 or more	3	.....

[1] An effort was made to ascertain the expenses of these men while following the harvest, but very few were able to give any satisfactory data on the subject.

Even if they live in the wheat belt men who travel through the harvest area, an empire in itself, incur relatively heavy traveling expenses. The high cost of travel discourages many of the best class of harvest hands from coming to the harvest a second time, while lack of money keeps many from going to points where they are badly needed. Thousands ride the freights or the "blind baggage" instead of paying their fares. It is a common practice of railroad crews to collect a dollar a man for such a ride from one division point to another. Men traveling in this way tend to drift through the harvest field, guided by chances to ride free rather than by known opportunities of employment. They waste their time and decrease the control of the distribution agencies over the labor supply. Often the grain they might be harvesting shatters while they are trying to "beat their way."

The employment officials, the farmers' organizations, and the agricultural officials are unanimous in the opinion that the harvest labor situation would be improved by the inauguration of harvest labor excursions to and from the harvest fields, which would bring the labor when it was needed and deposit it where it was needed. Kansas particularly has been trying to get special harvest rates for some time. At a meeting on March 15, 1920, at Hutchinson, Kans., it was decided to try for a 1-cent fare for harvest hands, but no agreement was reached with the railroad companies for a reduced rate for 1920. The issue, however, can not be considered closed. The following ruling from the secretary of the Interstate Commerce Commission shows the legality of such special rates: "It seems clear that the carriers could not lawfully grant reduced fares to farm laborers as such. The law, however, specifically allows carriers to establish rates or fares, and it might be possible for the carriers to establish special excursion fares that would be good to any who might desire to avail themselves of the fares."

In Canada the reduced-fare excursion has been found to be the most effective means for controlling the supply and distribution of labor in the harvest. The railroads run special harvest excursions from eastern to western Canada when labor is needed and check the flow of labor by taking off some or all of the excursions whenever the employment service signifies that it has enough men. If the railroads and the United States Employment Service were able to reach a similar understanding reduced-fare excursions from Chicago, Minneapolis, St. Louis, Omaha, Denver, and other points could be run at exactly the right time to move men to the harvest when they were actually needed, and the destination of the excursions could be fixed so as to provide an equitable distribution of the labor supply. At the same time it would be possible to check an excessive inflow of labor by stopping the excursions.

HARVEST WAGES.[4]

The workingman can not see why a given kind of work should draw higher pay at one time or place during the harvest than at another. When Kansas could give 70 cents an hour during the 1920 harvest, a 60-cent wage in Oklahoma or a 50 or 55 cent wage in the Dakotas looked like exploitation to the men. They could understand that a farmer with a poor crop can not afford to pay as high wages as one with a good crop, but the offers vary with the areas rather than with individual farmers. Why should wages be different in every State? Why should they vary in different counties in the same State?

The question is just as vexing from the farmer's point of view. "Why," says the Kansas farmer, "should I pay 70 cents for harvest labor, and the North Dakota wheat farmer pay only 50 or 60 cents?" "Why," says the North Dakota farmer, "do the Kansas farmers spoil the wage market by offering such exorbitant wages? We could get plenty of men for 50 cents if they had not paid 70 cents, but now we must pay 60 cents. They have encouraged the men to ask for excessive wages."

Similar variations in wages occur within a State and even within a county or township. Farmers in the same section offer different rates of wages, frequently stealing labor from one another by offering more than their neighbors. Harvesters in one locality accept a wage that others 10 miles away reject. In every section in North Dakota and Minnesota where wage data were collected the wages paid on different farms in the same neighborhood varied. In most cases the wages were fixed by individual bargains between the farmer and the men he hired. No generally accepted standard wage controlled this matter. Where the men were organized and had agreed upon a standard wage, the farmer was helpless in dealing with them; when men were plentiful and the farmers agreed among themselves, the men were forced to accept the wages offered.

In placing their orders with employment offices, and even when hiring men on the streets, many farmers in North and South Dakota offered "going wages" without specifying what they meant by the term. Sometimes the farmer's motive seemed to be a fear that if his neighbors found out what he was paying they might offer his men more. More frequently he was actuated by fear that he would offer more than others were paying, by a consciousness that he did not know what he ought to pay. This uncertainty, although not so common in Kansas, because of the 70-cent wage fixed by the Hutchinson meeting, prevailed more or less everywhere in the wheat belt.

[4] U. S. Dept. Agr. Bull. 943, "Cost of Producing Wheat," by M. R. Cooper and R. S. Washburn, gives a careful analysis of the labor cost in wheat growing.

It would appear, therefore, that two distinct needs with respect to harvest wages in the wheat belt should be satisfied as far as is practicable: (1) The need for a standard wage, known to everyone concerned, in each locality; (2) the need for wages as uniform as possible, with due consideration of the varying conditions in the different localities.

STANDARD WAGES.

There can be little question of the desirability of having a standard set in each State, either a standard wage for the State as a whole or standard wages for sections of the State. The farmer will then know what he must pay and what those who compete with him for labor will pay, and the harvester will know what wages to expect. If either of the interested parties is dissatisfied with the standard wage, it at least offers them a basis for bargaining.

In Kansas the standard wage which has been fixed by State meetings of farmers, in general, is set at the amount required to attract men away from city employment and pay for their railroad and other expenses to and from the wheat belt. In times of labor surplus in cities this wage may be low, but in normal times the harvest wage is higher than that for general unskilled labor.[5]

The purpose of the Kansas wage meeting is not to fix a low standard wage and force it upon the laborers, but to discover what wages are necessary to attract labor from outside the State to the harvest. A standard wage set too low in any year will cause a shortage of help and higher bidding on the part of the farmers to get the few men who come; one set too high will result in a surplus of men, a tendency to pay much less than the established wage, and loss of time to harvest hands. According to E. L. Rhoades, "the farmers of Kansas consider the wage conference not as collective bargaining but rather as a method of aiming at a reasonable conclusion as to what wages supply and demand would set in the State, if supply and demand had time to work the matter out to its logical conclusion. The farmers do not consider this a method of bargaining but as used to stabilize a price which will attract enough men to the State, and not too many."

UNIFORM WAGES.

None of the agricultural or employment officials interviewed believed that uniform wages are either desirable or practical. The

[5] Kansas Agric. Coll. Extension Circular 23 (March, 1921), "Kansas Handbook of Harvest Labor," by H. Umberger and E. L. Rhoades.

eastern sections of the wheat States are able each year to get labor more cheaply than the western sections can, while the wages in central and western Kansas and in the northwestern counties of North Dakota tend to be higher than those in the rest of the wheat belt. Since the bulk of the labor supply enters the wheat belt from the east, while the heavy wheat acreage, particularly in Kansas, is in the central and western counties, it costs less and is easier for harvest hands to reach work in the eastern counties, making it necessary for the central and western counties to add a little to the wage paid east of them. Furthermore, since the eastern counties have a much larger local labor supply, transient harvest hands must compete for work there, which tends to keep down the wages. Wages are lowest in the eastern counties, conform roughly to a "standard" wage in the central counties, and tend to rise above the standard in the more sparsely settled and less accessible western counties and at the outer extremities of spur lines of railroad, from which points movements to new territory is difficult.

Wages also vary from State to State, and this variation provokes much discussion among the harvest hands. The 45 cents an hour wage fixed by the Casselton, N. Dak., meeting for that portion of Cass County, caused many of the harvest hands working in the States to the south to refrain from going to North Dakota, because they thought 45 cents was a State wage. If a State with a small acreage, like Nebraska, however, attempted to pay wages as high as those paid in Kansas, it would be overrun with men unable to find work. The drop in wages which occurs between the Kansas and Nebraska harvests operates as a natural check to prevent thousands of Kansas harvesters from spending their money and time in a fruitless search for employment in Nebraska.

The essence of the matter seems to be that uniformity of wages, either between States or between the eastern and western sections of the same State, is impossible. The early arrivals in the Oklahoma and southeastern harvests are willing to accept whatever wages they can get during the first two weeks, in the hope of receiving higher wages when the harvest is in full swing in Kansas. Natural market conditions tend to raise the wages when Kansas and parts of Oklahoma are needing men at the same time. The contraction of the demand for labor as the Kansas harvest tapers off into the Nebraska harvest throws men out of employment, producing a fall in wages as the men compete for work there. North Dakota naturally endeavors to adhere to the lower rates, but is forced toward the Kansas price as its harvest nears its height. Neither interstate nor intrastate uniformity of wages seems feasible at present.

EFFECT OF EMPLOYMENT OFFICES UPON WAGES.

Farmers and some county agents on the one hand and the harvest laborers on the other frequently criticize the influence of the Government employment offices upon wages. These farmers and their friends have an idea that the offices raise the wages, while the men think that the offices depress them. While it may be true that an occasional employment official believes that wages are too low and rather encourages the men to "stick out" for a higher rate or considers the rates the men want too high and encourages the farmers in holding them down, the majority of the men in the Federal and State employment offices have tried to maintain an entirely neutral attitude on the question of wages and to act as impartial agents to bring the farmers and the men into contact with one another. A public employment office can follow only one policy successfully, and that is to fill all orders at the "going wage."[6] It can not force wages above that rate or depress them below it without destroying its business.

Wage rates in the harvest field are of two kinds, natural or unstandardized wages and standardized wages. In 1920 an effort was made to fix a standard wage in Kansas, where wages were for the most part unstandardized, to be paid regardless of the size of the labor supply.[7] The State employment offices naturally endeavored to adhere to this wage. If individual farmers refused to pay the rate fixed the office would accept their orders at lower rates, but inform them that it could hardly be expected to get men for them at 60 cents when most of the farmers were paying 70 cents. On the other hand, if a particular farmer placed an order at 80 cents, the office was justified in refusing to advertise the order at that price because if it offered the harvest hands one 80-cent job they would become dissatisfied with 70 cents. To post the 80-cent offer would "spoil the market." The only policy under which the employment offices could operate successfully in Kansas in 1920 was to adhere as closely as possible to the "going rate," 70 cents.

The ease with which the market can be "spoiled" was illustrated at Hays, Kans. A few days before the harvest opened a number of laborers sought employment there at the State rate, 70 cents an hour. After having waited a few days these men were called to the county agent's office in the city hall and an agreement made that they should be placed on farms at 70 cents an hour. Later that day, during the

[6] The expression "going rate" of wages is used here to signify that rate which the majority of farmers are willing to pay and at which labor can be secured for them. If a majority of the farmers offer a wage which the laborers refuse to accept, no "going rate" has been established.

[7] "Kansas Handbook of Harvest Labor," loc. cit.

absence of the county agent, some Russian farmers came to the city hall where most of the harvest hands were congregated, and said, "Boys, we are paying 75 cents an hour. How much do you want?" Seeing a chance to get more than 75 cents some of the laborers demanded 85 or 90 cents an hour, at which price the Russians hired them.[8] When the county agent returned to his office he found that the market had risen to 90 cents an hour, and that the men would not go out for 70 cents. Most of the farmers would not pay more than 70 cents, but there were enough of the Russians paying 90 cents or more an hour to take some of the harvesters and to prevent many of the others from accepting 70 or 80 cents. As a result there were on the streets most of the time about a hundred men, some of whom were honest, clean workers who really did not understand the situation. They listened to the more radical floaters who advised them not to work for less than $1 an hour and made them believe that they would receive that much if they "stuck."

In North Dakota, where no standard rate had been fixed by a State meeting, a group of farmers and a few townspeople at Casselton, Cass County, decided that they would pay 45 cents an hour in the harvest. As no effort was made to fix a standard by agreement in the rest of the State, there was a decided range in the wages offered. Different farmers and different localities were offering 50, 55, 60, and 70 cents an hour at the same time. Under these circumstances, what policy should the employment office at Fargo have followed with respect to harvest wages? Should it have tried to fill orders at all of these rates? At the lowest? At the highest? Could a grocer or a farmer sell the same commodity over the same counter at four different prices at the same time?

Practical experience in scores of cities in the United States, in Canada, and in England has demonstrated that there is only one policy which the employment office can follow in a situation of this kind. It must decide which rate is the actual "going rate" of wages and endeavor to fill as many of the orders as possible at that rate. Ordinarily it can not fill those below the "going rate"; and it can not advertise those above the "going rate" without spoiling the market.

CONCLUSIONS.

The continual fluctuation in harvest labor demand, caused by climate, pests, etc., makes it imperative that additional means be found to facilitate the spread of reliable information concerning harvest conditions among those who constitute the potential supply

[8] The diet in the homes of these Russian farmers differs from that in the homes of most farmers in the Central West. Consequently they have become accustomed to paying higher wages than their American neighbors.

of harvest labor. The daily bulletins issued by the Federal Employment Service during the winter-wheat harvest may be cited as an important step in this direction. Without the further development of such a service, the mobilization of the army of harvest laborers must remain largely a matter of guesswork.

Wildcat advertising by misinformed or unscrupulous persons causes the loss of much time and money, and even produces distress, among transient harvest hands. Newspapers outside of the wheat belt frequently are misled into giving publicity to erroneous statements about the demand for harvest labor.

Most of those who "make the harvest" get no more than a mere subsistence out of the venture. The comparatively small number who save money are those who, through fortunate location or foresight, are able to secure steady work without being forced to make long "jumps."

It seems desirable that a definite standard wage for each State, or perhaps for each distinct region within States, should be established annually.

While it is impossible that State or regional standards should be uniform, such standards should be as nearly uniform as possible under the prevailing conditions.

Employment offices must follow the policy of adhering to the "going wage."

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Contribution from the Bureau of Plant Industry
WM. A. TAYLOR, Chief.

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GROUP CLASSIFICATION AND VARIETAL DESCRIPTIONS OF AMERICAN VARIETIES OF SWEET POTATOES.[1]

By H. C. Thompson, formerly *Horticulturist*, and James H. Beattie, *Horticulturist, Office of Horticultural and Pomological Investigations.*

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IMPORTANCE OF VARIETAL CLASSIFICATION OF SWEET POTATOES.

To those familiar with the present state of sweet-potato nomenclature it is apparent that there is need for some simple system of classification by which varieties may be identified well enough to place them in the groups to which they belong. The need for such a classification is clearly shown by the large number of new names that each year are given to old varieties. The need is also readily

[1] Credit for the description of many of the varieties of sweet potatoes and for the working out of the system of classification contained in this bulletin is due F. J. Tyler, formerly assistant in botany of the Bureau of Plant Industry.

The main portion of the work was done by Mr. Tyler between 1902 and 1906; the addition of a number of important varieties not studied by Mr. Tyler and further work on all the varieties has necessitated changes in the key and in some of the descriptions.

During the progress of these investigations considerable work has been done by W. R. Beattie, horticulturist; Chester J. Hunn, assistant horticulturist; and H. M. Conolly, formerly assistant horticulturist, Office of Horticultural and Pomological Investigations, Bureau of Plant Industry.

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seen from a study of the literature on sweet potatoes. There being no recognized system of classification, the investigator uses a local name or the name under which the sweet potato was received. In either case the name may be entirely misleading or may have no significance.

While several hundred names are given to varieties of sweet potatoes grown in the United States, there are not over 40 true varieties. Not more than 10 of these varieties are of commercial importance, and 4 of them constitute the bulk of the commercial crop. Some of the important varieties are known under many different names. The Southern Queen, for example, is known under at least 20 different names, although Southern Queen and Hayman are by far the most common. Probably 90 per cent of the growers of this variety know it under one of the two names mentioned. Even such a well-known variety as Yellow Jersey is known under at least 10 names.

Giving new names to old varieties is very common, but is very confusing. In many cases the giving of a new name to an old variety is done because the true name is not known, but in other cases the new name is given for the purpose of deception. When a grower receives a sweet potato which is not known to him, he should make every effort to learn the correct name and not give it a name of his own choosing. There is certainly no excuse for renaming such well-known varieties as Southern Queen and Yellow Jersey, but it is the best-known varieties that have the greatest number of names.

To set forth a simple system of classification of sweet-potato varieties that will be of help to investigators, teachers, and growers is the purpose of this bulletin.

EARLY ATTEMPTS AT CLASSIFICATION.

The earliest important attempt at classifying the varieties of sweet potatoes was made by R. H. Price (55),[1] of the Texas Agricultural Experiment Station. Under this system sweet potatoes are classified into three groups based on the shape of the leaves, as follows:

(1) Varieties with entire or round foliage.
(2) Varieties with shouldered foliage.
(3) Varieties with deeply cut or lobed foliage.

After classifying sweet potatoes into the three groups by the typical shape of the leaves, each variety is described separately, but as no key is given except that referring to the shape of the leaves, it is not possible to determine a variety if the name is doubtful or unknown. The procedure to follow under this system is first to deter-

[1] The serial numbers in parentheses refer to the "Bibliography of sweet-potato literature" at the end of this bulletin.

mine to which of the three groups a given specimen belongs and then to read the descriptions of varieties until one is found which fits the specimen. This is a tedious and cumbersome method, although great credit is due the originator of this system, for it introduced some order into the previous chaotic condition. It is not possible, however, to identify many varieties without taking into consideration many points other than the shape of the foliage. The description given to the varieties is not sufficient to identify most varieties now grown.

Another classification of sweet-potato varieties that has been published is the one worked out by Groth (26). In this system the following factors are considered in making the key:

A. Shape of leaf.
- (1) Cut.
- (2) Round.
- (3) Long.
- (4) Broad.
- (5) Mixed (round and lobed).

B. Size of leaf.
- (1) Small (less than 4 inches across).
- (2) Large (more than 4 inches across).

C. Length of stem.
- (1) Long (more than 4 feet long).
- (2) Short (less than 4 feet long).

D. Color of stem.
- (1) Green (with or without brownish areas).
- (2) Green (with purple around the axils of the leaves).
- (3) Greenish brown to purple.
- (4) Purple.

E. Size of stem.
- (1) Thin (less than one-eighth of an inch in diameter).
- (2) Thick (more than one-eighth of an inch in diameter, often three-sixteenths or more).

F. Presence or absence of star.
- (1) Star present.
- (2) Star absent.

G. Color of lower surface of veins.
- (1) Vein purple.
- (2) Midrib pinkish in some old leaves.
- (3) Purple spot at base of midrib.
- (4) Veins all green.

H. Arrangement of hair on the upper surface of the leaf, if any.
- (1) Hair all over.
- (2) Chiefly on tips and along veins.
- (3) Absent.

I. Outside color of the roots.
- (1) White.
- (2) Yellow, golden, or bronze.
- (3) Yellow, red, or pinkish.
- (4) Red or purple.

J. Color of flesh of the roots.
- (1) White.
- (2) Cream colored or yellowish white.
- (3) Pinkish white or pinkish yellow.
- (4) Pinkish orange.
- (5) Marked with purple.

K. Distinctness of wood elements in the root.
- (1) Distinct.
- (2) Blurred.
- (3) Not visible.

While most of these characteristics are very important, some of them vary so much under different environmental conditions that their use in a key is of doubtful value. The size of the leaf and size and length of the stem vary so much under different soil and climatic conditions that measurements made under one set of conditions do

not fit under different conditions. It is well known that the length of vine of any variety is greater in the South than in the North. The length and size of the vine, as well as the size of the leaf, are greater on heavy soils than on light sandy soils. In the description of the Nancy Hall variety the stem is classed as short (under 4 feet long), while in practically every region where this variety is grown to any great extent the stem grows to be more than 4 feet in length. In the vicinity of Washington, D. C., on a sandy-loam soil the stems grow 4 to 8 feet long. The vine of the Shanghai variety is also classed as short, but under the conditions mentioned in connection with the Nancy Hall it grows to be 6 to 9 feet in length. The stems of the Ticotea and Florida varieties are also classed as short, while under fairly favorable conditions they grow to a length of 6 to 9 or 10 feet.

The other characters used in the key, with the possible exception of the "Arrangement of hair on the upper surface of the leaf, if any," and "Distinctness of wood elements in the root," are very important and reliable. All characters should be considered in connection with the mature plant, as many do not develop on new growth and some disappear as the plant nears maturity. The shape of the leaves on new growth is often very different from the shape of fully developed leaves. The surface of young leaves may be covered with hairs, while older leaves may be entirely smooth. The use of letters and numbers rather than the terms for which they stand makes the key rather awkward.

Another attempt at classification of sweet-potato varieties is given in Bulletin 33, "Estacion Experimental Agronomica," Santiago de las Vegas, Cuba, entitled "Las Variedades Cubanas de Boniato." This work deals to a certain degree with American varieties, much of the material having been obtained in this country. In this system of classification four groups—white, yellow, purple, and reddish—are made, and these are further divided according to the color of the stems, leaves, and veins on the leaves. This system of classification is not sound, as the color of the roots varies greatly with difference in soil and climatic conditions.

PROPOSED SYSTEM OF CLASSIFICATION.

The work on which the proposed system of classification is based was begun by the Bureau of Plant Industry in 1901 and has been continued up to the present time. During the season of 1901 the varietal work was carried on at College Park, Md., in cooperation with the Maryland Agricultural Experiment Station. At the end of the season, the work and the varietal collection were transferred to the Bureau of Plant Industry. From 1902 to 1920 the collection has been grown every year on the Potomac Flats, near Washington. The

soil selected has ranged from sand to a fine sandy loam. Most of the studies have been made from the crops grown at Washington, but the varieties have also been grown at Baton Rouge, La., Florence, S. C., Norfolk, Va., Columbus, Ohio, and Watson, N. Y., for the purpose of studying their behavior under different environments. The varietal descriptions were checked with the collections grown at all of the points mentioned.

During the years the work has been in progress it has been the aim to test all varieties that are grown in the United States. New varieties have been added from time to time, and many so-called new varieties have been grown, only to find that they were old varieties given new names. It is believed that practically all varieties now grown in the United States are included in the present collection. All the important sweet-potato growing regions have been visited by those engaged in the work, and wherever a variety was found which was not definitely known it was added to the collection for study and comparison with the varieties being grown in the test.

Before attempting to classify the varieties of sweet potatoes, careful descriptions were made of all varieties. Those showing a marked similarity were grouped together in the field for further comparison. It has been found that all the varieties that have been grown can be placed in eight well-defined groups, each group being distinct and easily recognized. By means of a simple key, the group to which any variety belongs can be determined very easily and quickly. Each group has been given the name of the most widely known variety or the variety that is most typical of that group. Three of the large groups have been divided into sections to simplify the procedure of identification. It is believed that this grouping of varieties makes identification comparatively easy. After determining the group to which a variety belongs by means of the key the group description should be read to determine the section and the variety. To make sure of the correctness of identification, the descriptions of all varieties in the group should be read.

As indicated in previous pages, no one character can be depended on to establish the identity of any sweet-potato variety; but rather a combination of characters, such as the length and character of the vines and the size, shape, and color of the roots. While typical specimens of such varieties as the Porto Rico, Big-Stem Jersey, Nancy Hall, Triumph, Yellow Strasburg, Southern Queen, and Pumpkin may be described as fusiform to globular, long fusiform, fusiform, medium to long cylindrical, globular, or ovoid in shape, an inspection of Plates I, II, and III, which show the variation in the size and the shape of several specimens of each of these varieties, will show how great the variations in size and shape within the variety really are.

In giving the names of the varieties it would be desirable to consider priority of nomenclature, but it is not possible to establish priority. In most cases it has not been possible to determine when, where, and by whom a name was given; therefore it has been deemed advisable to select the name that is in most general use. It is realized that growers in some sections will feel that some of the names used in this bulletin are not the correct ones. Growers in Viriginia may insist that the name Hayman should have been used instead of Southern Queen, but the latter name is more common in all other sweet-potato growing regions. The name Nansemond is more common than Yellow Jersey in Virginia, but the latter name is much more common in all other regions where this variety is grown. The same may be said of all other names selected to designate the important varieties. Some varieties are grown to such a limited extent that there is not much chance for confusion.

KEY TO THE GROUPS.

I. Leaves deeply lobed or parted—1 and 2.
- (1) Leaves with purple stain at the base of the leaf blades. TICOTEA, page 6.
- (2) Leaves without purple stain at the base of the leaf blades. BELMONT, page 7.

II. Leaves not deeply lobed or parted—1 and 2.
- (1) Leaves with purple stain at the base of the leaf blades—*A* and *B*.
  - (*A*) Stems purple or greenish with decided tinge—SPANISH, page 8.
  - (*B*) Stems—*a* and *b*.
    - (*a*) Leaves entirely to slightly shouldered; roots white. SHANGHAI, page 8.
    - (*b*) Leaves toothed with 6 to 10 low marginal teeth, or entire; roots salmon or yellow tinged with salmon. FLORIDA, page 9.
- (2) Leaves without purple stain at the base of the blade or with very faint stain—*A* and *B*.
  - (*A*) Stems purple—SOUTHERN QUEEN, page 9.
  - (*B*) Stems green—*a* and *b*.
    - (*a*) Stems medium to large in size; roots fusiform, yellow tinged with salmon, with light yellow veins—PUMPKIN, page 9.
    - (*b*) Stem slender; roots russet yellow or red, ovoid to fusiform—JERSEY, page 10.

DESCRIPTIONS OF THE GROUPS.

In the descriptions of the groups an effort has been made to give the characteristics of the vines and roots of the entire group and not that of any particular variety; in fact, the group description has been made from the descriptions of the varieties belonging to the group.

TICOTEA GROUP.

Vines long, 6 to 12 feet, or short and stocky; stems green in color or with a tinge of purple at the nodes, nearly smooth; leaves very angular in outline, 5 to 7 lobed; blade hairy only on the veins of the upper surface, green except

for a deep purple stain at the base of the blade and the summit of the petiole; the latter otherwise green, hairy, or nearly smooth. Roots white, smooth, without veins or ribs, varying from fusiform to cylindrical in shape, of medium to large size; flesh white, but dull or grayish white or light yellow when baked, only slightly sweet, quite dry and mealy, and firm in texture. Flavor not pronounced.

The Ticotea group contains only two varieties, Ticotea and Koali, and is not important.

BELMONT GROUP.

Vines medium to long, 4 to 12 feet, or very short, 1 to 3½ feet; stems slender or thick and coarse, green, hairy, or smooth to nearly smooth; leaves deeply 5 to 7 lobed, upper surface of blade hairy to nearly smooth, lower surface smooth or slightly hairy along the veins, green in color; petiole also green, hairy, or smooth. Roots light salmon, yellow tinged with salmon, russet yellow, or rose to purple; veins often prominent and always lighter in color than the rest of the surface; the roots usually fusiform, smooth except for the veins, of average size; medium to late in season; flesh white, yellow, light salmon to dark salmon in color, but light yellow, dark yellow, or yellow tinged with salmon when baked, sweet to very sweet, and so moist that sirup can be squeezed out with slight pressure; flavor somewhat squashlike; texture soft or at times rather coarse and stringy.

The Belmont group may be divided into two sections, as follows:

Belmont section: Vines long and creeping.

Bunch section: Vines very short and bushy.

The stems of the varieties of the Belmont section are long and slender, from 6 to 12 feet in length; or medium in length, 4 to 8 feet, with internodes 2 to 4 inches long. The leaves are rather small, with narrow lobes, except that those of the Eclipse Sugar "yam"[1] and Vineless Pumpkin "yam" are larger, with broad ovoid lobes.

The following varieties belong to the Belmont section:

(1) Belmont. (This variety or very slight variations of it is known under the names Georgia and Dunton's Improved.)
(2) Eclipse Sugar "yam."
(3) Vineless Pumpkin "yam." (Pl. IV, figs. 1 and 2.)
(4) Old Time "yam."
(5) Yellow "yam."
(6) White Sealy.

The stems of the Bunch section are thick and coarse and from 1 to 3½ feet long, with internodes one-third to one-half an inch long, the leaves being greatly crowded in consequence, and it follows that the total leaf surface of a Bunch vine 18 inches long is nearly or quite equal to that of a Belmont vine 11 to 12 feet in length. The leaves resemble those of the Eclipse variety in being large, with broad ovoid lobes.

The following varieties belong to the Bunch section:

(1) Gros Grandia.
(2) Bunch Candy "yam." (Also called Bunch "yam," Vineless, Prolific, and Gold Coin.) (Pl. IV, fig. 3.)

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[1] The term "yam" used in this key to designate certain varieties of sweet potatoes is used because it is a varietal designation and not because it refers to a yam. The term "yam" when applied to sweet potatoes is a misnomer, as the true yams belong to an entirely different genus, Dioscorea. Yams are grown to a limited extent only in the more southerly portions of the South, principally Florida, and are of little commercial importance.

SPANISH GROUP.

Vines medium in length, 4 to 10 feet or 6 to 15 feet long (vines of Red Brazil and Creola sometimes grow to be 20 feet long), or short and bushy, 2 to 3 feet, coarse, dark purple in color or green with purple tinge, hairy (especially at the nodes) or smooth; leaves deeply shouldered to entire, green except for a deep purple stain at the base of the blade and the summit of the petiole. The color may extend up the veins, hairy on the upper surface or only on veins, or smooth, the under surface smooth or slightly hairy; petiole green tinged with purple toward the summit, or deep purple. Roots red, yellow, russet yellow, or yellow tinged with rose, usually very irregular, being strongly ribbed and veined or smooth; fusiform, ovoid, or long cylindrical in shape; medium to very large in size, ripening either early or late. Flesh white, yellow, dull yellow, cream, salmon yellow, or dark yellow. When baked, sightly sweet to very sweet, moist to dry and mealy, firm or soft in texture. Flavor caramellike, but not pronounced.

The varieties in the Spanish group may be separated into three sections, as follows:

(1) Yellow Spanish: Roots light yellow to russet yellow.
(2) Bermuda: Roots light yellow, yellow tinged more or less with rose or deep rose.
(3) Red Spanish: Roots dark red to purple.

In the Yellow Spanish section the roots are light yellow in color, usually very irregular, strongly ribbed and veined, but sometimes fairly smooth and regular; flesh white or yellow. The earliest varieties are contained in this section, being listed as follows:

(1) Pierson. (This same variety or variations of it is known under the names of Arkansas Beauty, California Golden, Early General Grant, Golden Skin, and Dutton's Early.)
(2) Yellow Strasburg. (Also called Extra Early Golden and Adams.) (Pl. IV, fig. 4, and Pl. V, fig. 1.)
(3) Yellow Spanish. (Also called Bronze Spanish.)
(4) Triumph.

The roots of the Bermuda section are light yellow, more or less overlain with transverse dashes and bands of rose, sometimes washed with rose, or deep rose to purple, usually very irregular, strongly ribbed and veined; but some varieties are quite smooth and regular. The varieties are medium early, being listed as follows:

(1) Red Bermuda. (Also known as Cuba "yam," Poreland, Yellow Red.)
(2) Red Brazil or Red Brazilian.
(3) Porto Rico. (Also called Golden Beauty and Key West "yam.")
(4) Key West "yam."
(5) Creola.

Roots of the Red Spanish section are more regular and are not constricted; the flesh is white, tinged with purple beneath the skin and at the center. The section contains the following varieties:

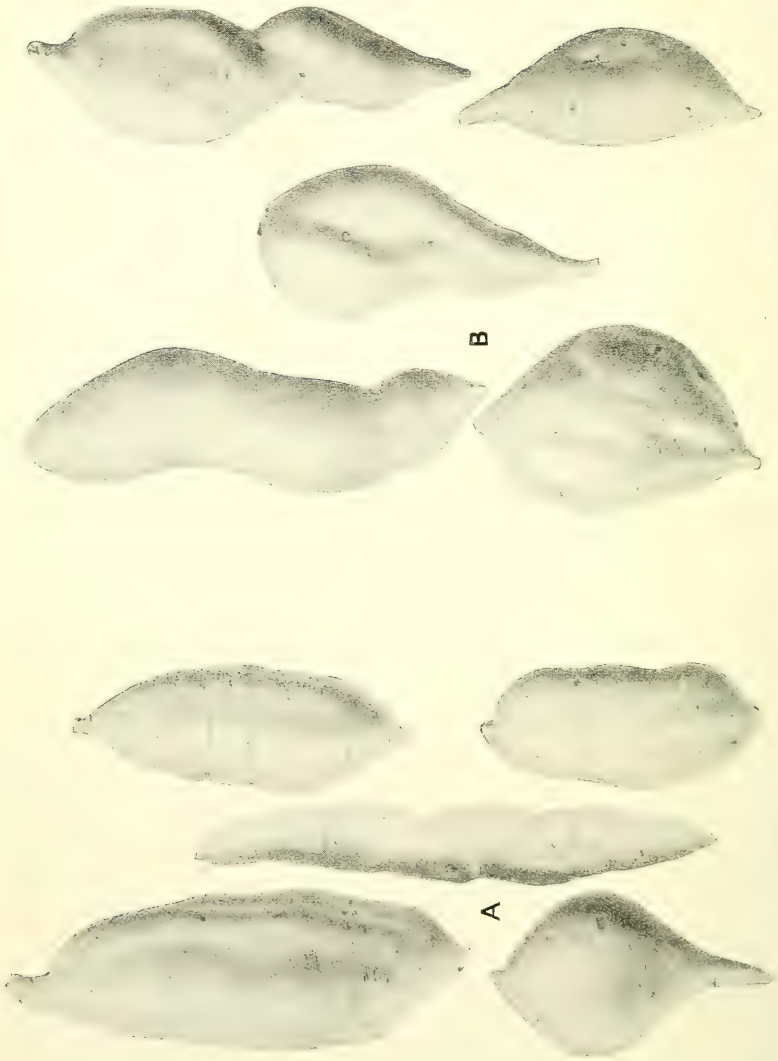
(1) Red Spanish. (Also called Black Spanish.)
(2) Purple "yam," or Nigger Choker.
(3) Dahomey.

SHANGHAI GROUP.

Vines medium to long, 5 to 10 feet, or long, 8 to 16 feet; stems coarse and thick, green in color and hairy, especially at the nodes; leaves large, entire, or sometimes shouldered, hairy at first, but later smooth except for scattered hairs

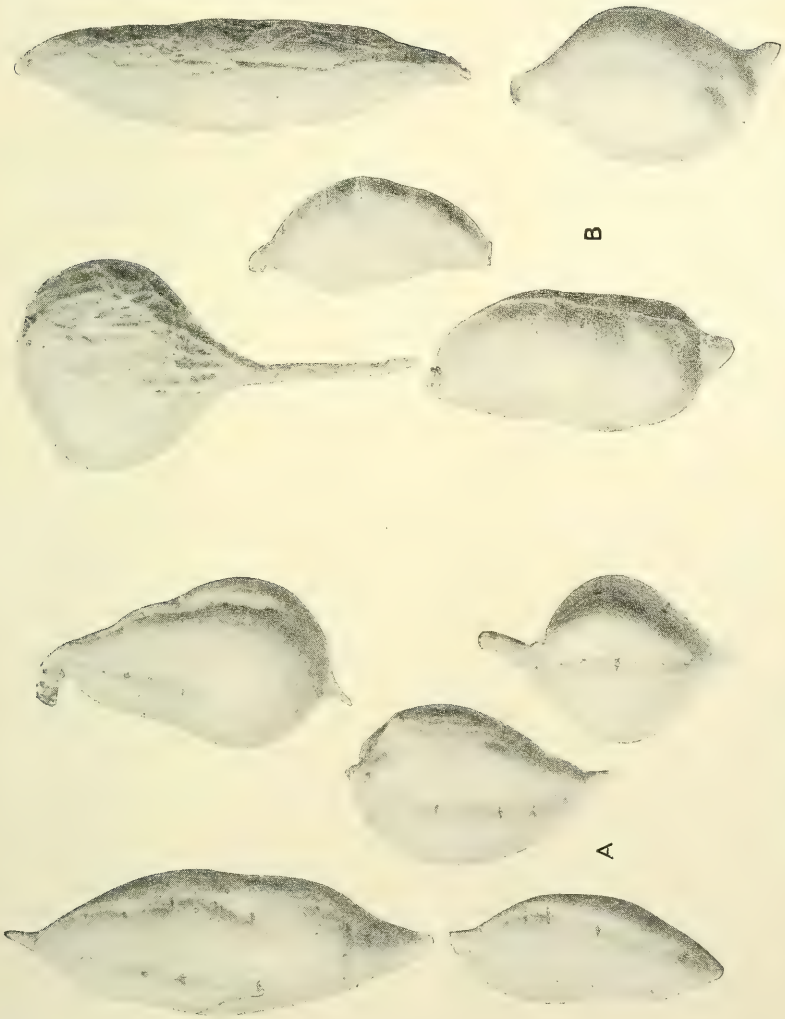
A, Porto Rico. *B*, Big-Stem Jersey. *C*, Nancy Hall.

VARIATION IN THE SIZE AND SHAPE OF VARIETIES OF SWEET POTATOES. I.



A, Triumph. *B*, Yellow Strasburg.

VARIATION IN THE SIZE AND SHAPE OF VARIETIES OF SWEET POTATOES. II.



A, Southern Queen.

B, Pumpkin "Yam."

VARIATION IN THE SIZE AND SHAPE OF VARIETIES OF SWEET POTATOES. III.

AMERICAN VARIETIES OF SWEET POTATOES. I.

FIG. 1.—The Vineless Pumpkin Yam, a representative of the Belmont group, Belmont section. FIG. 2.—Mature and immature foliage of the Vineless Pumpkin Yam. FIG. 3.—Bunch Candy Yam, a representative of the Belmont group, Bunch section. FIG. 4.—Yellow Strasburg, a representative of the Spanish group, Spanish section; a heavy yielder of very irregular potatoes of fair quality.

American Varieties of Sweet Potatoes. II.

Fig. 1.—Young and old foliage of Yellow Strasburg. Fig. 2.—Triumph, a representative of the Spanish group, Spanish section; a heavy yielder of roots that are often very irregular. Fig. 3.—Porto Rico, a representative of the Spanish group, Bermuda section. Fig. 4.—Foliage of Porto Rico, one of the best varieties.

on the veins above, green except for a deep-purple stain at the base of the blade and the summit of the petiole. The purple color runs to the larger veins of the leaf to some extent; petioles green except at upper end, hairy to some extent. Roots white in color, smooth, and regular or veined and ribbed, long cylindrical to fusiform in shape, medium to large in size, and very late in season; flesh yellow or dull grayish white. When baked, only slightly sweet, dry, and mealy, and rather firm in texture. Flavor not pronounced.

The Shanghai group contains the following varieties.

(1) Shanghai. (Also called Early Golden and California.)

(2) Minnet "yam."

FLORIDA GROUP.

Vines medium to long, 4 to 10 feet; stems rather coarse and thick, green, smooth or somewhat hairy at the nodes, or they may be hairy all over; leaves entire or toothed, with 6 to 10 low marginal teeth, hairy or smooth, except for scattered hairs on the veins on the upper surface, green except for a deep-purple stain at the juncture of the blade and the petiole, this color passing to the large veins of the leaf and down the petiole a short distance; petiole otherwise green and smooth or somewhat hairy; roots light yellow or yellow tinged with salmon; veins when present lighter in color than the rest of the surface, short to long, fusiform in color, of medium to large size, season medium; flesh yellow or yellow tinged with salmon to dark salmon, but light yellow to dark orange yellow when baked; sweet to very sweet, and sugary, very moist to quite dry; the texture soft and melting or sometimes rather coarse; flavor good.

The following varieties belong to the Florida group:

(1) Florida. (Also called Arizona Prolific and Providence.)

(2) General Grant Vineless.

(3) Nancy Hall.

SOUTHERN QUEEN GROUP.

Vines large and vigorous, long, 6 to 12 feet; the stems thick and coarse, dull purple in color, hairy throughout the length, somewhat hairy at the nodes and on new growth, or smooth; leaves shouldered or sometimes entire, slightly hairy above, smooth beneath, green; petiole greenish purple and nearly smooth or hairy (especially at the base). Roots white or light yellow and sometimes very slightly tinged with pink around the upper end, fairly smooth and regular, or somewhat ribbed and veined, globular or short, fusiform in shape or long fusiform; medium to large in size; season medium. Flesh light yellow, sweet, very moist to fairly dry, soft in texture or very fibrous; flavor good.

The following varieties belong to the Southern Queen group:

(1) White "yam."

(2) Southern Queen. (This variety, or slight variations of it, is known under the following names: California "yam," Arkansas Hybrid, Brazilian, Cuban, Common "yam," Hayman, Johnson's Bahama, Kentucky White, McCoy, Polo, Vestal's Newark, Miles "yam," Archers' Hybrid, Hamburg, Caroline Lee, Cullman Cream "yam," Hanover, Catawba White, and Ballinger's Pride.)

PUMPKIN GROUP.

Vines long, 6 to 15 feet; stems small to average size, green, slightly hairy (especially at the nodes and on new growth); leaves low, shouldered, or entire with 4 to 10 low marginal teeth, hairy on the upper surface of the blade and smooth beneath, green; petiole green, slightly hairy (especially near its

base). Roots yellow, tinged with salmon, fusiform to cylindrical in shape, veined prominently and often slightly ribbed, the veins light yellow in color, medium to large in size, season late. Flesh yellow to deep orange-yellow. When baked, sweet to very sweet, very moist and soft in texture, flavor distinctly like squash.

The Pumpkin group contains the following varieties:

(1) Pumpkin "yam." (Early Yellow, or Spanish "yam.")
(2) Norton.
(3) Dooley.
(4) White Gilke.

JERSEY GROUP.

Vines low and slender to large in growth very short, 1 to 2½ feet, or long, 6 to 15 feet; stems very slender to thick and coarse, green, hairy (especially at the nodes); leaves shouldered to entire (both extremes may be found on the same vine), green, sometimes a very slight tinge of purple may be found at the juncture of the blade and the petiole especially in the Red Jersey section, smooth or hairy on the upper surface of the blade, slightly hairy, or smooth beneath; petiole green, hairy (especially at the lower end). Roots red or russet yellow in color, usually very regular in shape, smooth or veined more or less, short to long fusiform or even globular, small to large in size, season early to late; flesh light yellow to dark yellow. When baked, fairly sweet, usually very dry and mealy, and quite firm in texture.

The Jersey group contains the varieties usually found on the northern markets. These may be divided into the following sections:

(1) Roots red ..... Red Jersey.
(2) Roots russet yellow.
  Stems short and bushy ..... Bush.
  Stems long.
    Stems medium to large ..... Big-Stem Jersey.
    Stems slender ..... Yellow Jersey.

Varieties of the Red Jersey section have stems varying from slender to coarse, often fasciated; roots light russet, red, or dark red, medium in size, usually fusiform or ovoid, sometimes globular in shape; season medium to late; flesh golden brown. When baked, sweet, dry, and mealy; quite firm in texture.

The following varieties belong to the Red Jersey section:

(1) Japan Brown.
(2) Red Jersey. (Also called Connelly's Early Red, Early Red Carolina, Red Nansemond, and Van Ness Red.)

The stems of the Bush section are very short, 1 to 2½ feet, rather thick and coarse, with very short internodes and crowded leaves, the internodes one-third to one-half inch long; leaves hairy on the upper surface, but more shining than those of the Yellow Jersey section, usually entire or slightly shouldered; roots russet yellow, fusiform to ovoid in shape, medium in size, season medium; flesh yellow. When baked, the flesh is fairly sweet, dry, and mealy, quite firm in texture.

The Bush section contains but one variety, the Vineland Bush. (Also called Georgia Buck "yam" and Vineless Bunch Nansemond.)

In the Big-Stem Jersey section the vines are moderately large growing, long, 6 to 12 feet; stems rather thick and coarse, often fasciated; leaves larger than those of the Yellow Jersey section, strongly shouldered to entire. Roots russet yellow, often strongly veined, but otherwise smooth and regular, usually fusiform in shape, but inclined to become ovoid, medium to large in size; season medium, flesh light yellow. When baked, the flesh is usually very dry and mealy and quite firm in texture; flavor chestnutlike.

The Big-Stem Jersey section contains the following varieties:

(1) Big-Stem Jersey, sometimes called Florida and Improved Big Stem.

(2) Philipili.

The Yellow Jersey section has vines that are very small and slender to moderately large in growth, long, 6 to 12 feet; stems slender, often fasciated. Roots russet yellow, smooth and regular, or with low veins, fusiform or globular in shape, small to medium in size, season medium; flesh light yellow to salmon. When baked, usually very dry and mealy and quite firm in texture.

The Yellow Jersey section contains the following varieties:

(1) Yellow Jersey. (Other names given to this variety or selections of it are the following: Early Bloomer Nansemond, Big Leaf, Early Carolina, Early Yellow Jersey, Kelly's, McCoy's Sweets, Red Nose, Nansemond, Yellow Nansemond, Up River, Cedarville.)

(2) Gold Skin.

LIST OF VARIETIES INCLUDED IN THE KEY.

	Page.		Page.
Belmont	12	Porto Rico	14
Big-Stem Jersey	18	Pumpkin "yam"	16
Bunch Candy "yam"	13	Purple "yam" or Nigger Choker	15
Creola	14	Red Bermuda	14
Dahomey	15	Red Brazil	14
Dooley	17	Red Jersey	17
Eclipse Sugar "yam"	12	Red Spanish	15
Florida	15	Shanghai	15
General Grant Vineless	16	Southern Queen	16
Gold Skin	18	Ticotea	11
Gros Grandia	13	Triumph	14
Japan Brown	17	Vineland Bush	17
Key West "yam"	14	Vineless Pumpkin "yam"	12
Koali	11	White Gilke	17
Minnet "yam"	15	White Sealy	12
Nancy Hall	16	White "yam"	16
Norton	17	Yellow Jersey	18
Old-Time "yam"	12	Yellow Spanish	13
Philipili	18	Yellow Strasburg	13
Pierson	13	Yellow "yam"	12

DESCRIPTIONS OF VARIETIES.

TICOTEA. (TICOTEA GROUP.)

Vines large and vigorous, long creeping, 6 to 12 feet; stems green or with a slight tinge of purple at the nodes, nearly smooth; leaves 5 to 7 parted, hairy only along the veins on the upper surface, green except for a deep-purple stain at the blade and the summit of the petiole, the latter otherwise green and hairy; roots white, smooth, and regular, usually very long and cylindrical in shape, medium to large in size, season very late; flesh white, but dull grayish white when baked, only slightly sweet, quite dry and mealy; firm in texture.

This is not an important variety.

KOALI. (TICOTEA GROUP.)

Vines short and stocky; stems green or with a purple tinge at the nodes, smooth or only slightly hairy at the nodes, coarse; leaves deeply 5 to 7 lobed; deep-purple stain at the base of the leaf blade, this purple coloring extending

over veins on the under side of the leaf; petiole with purple stain near the base and at the summit, otherwise green, slightly hairy; roots white, cylindrical, medium in size, season late; flesh white, but light yellow when baked; mealy; firm in texture, only slightly sweet.

This variety is not grown in this country except in an experimental way.

BELMONT. (BELMONT SECTION, BELMONT GROUP.)

Vines slender and low, long creeping, 6 to 12 feet; stems light green, hairy; leaves 5 parted with basal lobes inclined to shoulder, hairy above and upon the veins beneath, light green; petiole hairy, green; roots dark yellow with prominent light-yellow veins, fairly smooth and regular, long fusiform in shape, medium in size; season late; flesh golden yellow, but dark yellow when baked, sweet, moist, and soft in texture.

ECLIPSE SUGAR "YAM." (BELMONT SECTION, BELMONT GROUP.)

Vines somewhat larger and coarser in growth than is typical for this section, long creeping, 6 to 12 feet; stems hairy, light green; leaf characters similar to those of the Belmont variety except that the blade is larger and the lobes broader; petiole green, hairy; roots light salmon in color, with prominent light-yellow veins, otherwise smooth and regular, fusiform in shape, medium to large, season late; flesh yellow, tinged with salmon. When baked, sweet, moist, and soft in texture.

VINELESS PUMPKIN "YAM." (BELMONT SECTION, BELMONT GROUP.)

Vines of medium length, 4 to 8 feet; stems green, slightly hairy, especially at the nodes; leaves 5 to 7 parted, hairy above, nearly smooth or slightly hairy upon the veins underneath, green; petiole nearly smooth, green; roots yellow, tinged with salmon, slightly russeted, with a few low, light-yellow veins, fusiform to ovoid, or cylindrical, medium in size, smooth; season late; flesh salmon, with patches of light yellow. When baked, dark yellow to salmon, very sweet and moist; fairly firm in texture.

OLD-TIME "YAM." (BELMONT SECTION, BELMONT GROUP.)

Vines low and slender in growth, long creeping, 6 to 12 feet; stems green, hairy; leaves 5 to 7 parted, hairy above, nearly smooth beneath, green; petiole green, hairy; roots light yellow, somewhat russeted, with prominent light-yellow veins, otherwise smooth and regular, fusiform to cylindrical, medium in size; season late; flesh light yellow. When baked, very sweet, moist, and soft in texture.

YELLOW "YAM." (BELMONT SECTION, BELMONT GROUP.)

Vines low and slender, long creeping, 6 to 12 feet; stems green, hairy; leaves 5 to 7 parted, hairy above and slightly hairy beneath, green; petiole green, hairy (especially at the base); roots yellow, tinged with salmon, with low, very light-yellow veins, fusiform in shape, regular, medium in size; season late; flesh yellow, streaked with salmon, salmon ring just under outer skin. When baked, sweet and moist; soft in texture.

WHITE SEALY. (BELMONT SECTION, BELMONT GROUP.)

Vines medium in length, 4 to 6 feet; stems medium to coarse, green; leaves deeply 5 to 7 lobed, finely cut, green with purple tinge on new growth and at base of petiole, smooth on upper surface and smooth beneath; petioles medium

length, green with tinge of purple at upper end on new growth, smooth; roots long, cylindrical, yellow to russet yellow, smooth; flesh light yellow, but grayish white when baked; dry and mealy, decided caramel flavor, but not sweet; only fair in quality.

GROS GRANDIA. (BUNCH SECTION, BELMONT GROUP.)

Vines short to vineless, 1½ to 3 feet; stems very coarse, green, nodes very close, smooth except for a few hairs on the newer growth; leaves deeply 5 to 7 lobed or parted, upper surface nearly smooth or slightly hairy, lower surface smooth; petioles smooth or with a few scattered hairs on the new growth, green; roots long, cylindrical, veins slightly raised, numerous but fine, rose to purplish red in color; flesh white. When baked, moist and poor in quality.

BUNCH CANDY "YAM." (BUNCH SECTION, BELMONT GROUP.)

Vines very short and bushy, 1 to 3½ feet, but medium to vigorous in growth; stems green, nearly smooth, internodes very short, crowding the leaves closely together; leaves 5 to 7 parted, lobes somewhat broader than those of the Belmont variety, hairy above and smooth beneath, light green; petioles nearly smooth, green; roots light yellow, tinged with salmon, slightly russeted, light-yellow veins, small and regular, long spindle or fusiform in shape, small to medium in size; season late; flesh light yellow. When baked, sweet and moist; soft in texture.

PIERSON. (YELLOW SPANISH SECTION, SPANISH GROUP.)

Vines large and vigorous, long creeping, 6 to 15 feet; stems purple in color, hairy; leaves shouldered, hairy only on the veins above, green with a deep-purple stain at the juncture of the blade and the petiole, the latter nearly smooth, green except at the upper end; roots light yellow, strongly ribbed and veined, very rough, fusiform and ovoid in shape, medium to very large; season early; flesh cream color, but dull yellow when baked; only slightly sweet, moist to quite dry and mealy; texture firm.

YELLOW STRASBURG. (YELLOW SPANISH SECTION, SPANISH GROUP.)

Vines large and vigorous, long creeping, 6 to 15 feet; stems purple in color, nearly smooth; leaves shouldered, slightly hairy above, especially on new growth, green except for a deep-purple stain at the juncture of the blade and the petiole, the latter otherwise green or purple (both colors may appear on the same vine), nearly smooth, roots light yellow, fairly smooth and regular or quite irregular, ovoid or globular in shape, medium to large, season early; flesh dull yellow when baked, sweet, moist, and quite soft in texture.

YELLOW SPANISH. (YELLOW SPANISH SECTION, SPANISH GROUP.)

Vines moderately large in growth, long creeping, 6 to 12 feet; stems dark purple in color, somewhat hairy; leaves deeply shouldered, smooth or with scattered hairs on the midrib and margin of the leaf, dark green, with purple veins, petiole nearly smooth, purple; roots dull russet yellow, often constricted and crooked, fairly smooth, with no veins, long fusiform to long cylindrical, medium in size, season late; flesh grayish white; when baked, fairly sweet, moist, and soft in texture.

TRIUMPH. (YELLOW SPANISH SECTION, SPANISH GROUP.)

Vines coarse and vigorous, short, 2 to 4 feet, bushy; leaves shouldered, large and thick, hairy on veins of upper surface, smooth beneath; petioles green, with purple stain at the base of the leaf blade and extending up the veins on the under surface of the leaf; roots medium to long cylindrical in shape, light yellow to russet yellow in color; flesh light yellow, but creamy yellow when baked, medium moist to dry, fairly sweet, and firm in texture. (Pl. V, fig. 2.)

RED BERMUDA. (BERMUDA SECTION, SPANISH GROUP.)

Vines large and vigorous, long creeping, 6 to 12 feet; stems purple in color, hairy; leaves shouldered, slightly hairy above, green except for a deep-purple stain at the base of the blade and the summit of the petiole, the latter green or purple, nearly smooth; roots deep rose or reddish purple, irregular, strongly ribbed, short fusiform, globular, or ovoid in shape, medium to large, season medium; flesh light yellow, but dull yellow when baked; only slightly sweet, dry, and somewhat mealy; firm in texture.

RED BRAZIL. (BERMUDA SECTION, SPANISH GROUP.)

Vines long to very long, 6 to 20 feet, vigorous; stems medium coarse, purple in color, hairy, especially at the nodes on new growth; leaves shouldered to entire, slightly hairy on the upper surface, smooth beneath, deep-purple stain at the base of the blade; petioles green or purplish green, color running up along the veins on the under side of the leaf, deep purple at summit, slightly hairy at base; roots globular, irregular, surface rose in color; flesh dark yellow, but dark golden yellow when baked; sweet, fairly mealy, good quality; season medium to late.

PORTO RICO. (BERMUDA SECTION, SPANISH GROUP.)

Vines medium to long, 5 to 10 feet; stems coarse, internodes short, reddish purple in color, hairy (especially at the nodes and on young growth); leaves shouldered, large in size, green except for a purple stain at the base of the blade and on the veins, slightly hairy on the upper surface, smooth below; petioles medium long, 5 to 8 inches, reddish purple in color, deeper at the base of the leaf blade, color extends to the veins on the lower side of the leaf and also deeper at the base of the petiole; roots light rose to rose in color, fusiform to globular and irregular in shape, smooth; flesh orange yellow to salmon, but dark yellow when baked; moist, very sweet, good quality.

This is one of the most popular varieties in the South, especially where it is well known. (Pl. V, figs. 3 and 4.)

KEY WEST "YAM." (BERMUDA SECTION, SPANISH GROUP.)

Vines medium to long, 4 to 10 feet; stems coarse, hairy, dark purple in color, internodes short; leaves deeply shouldered, upper surface nearly smooth, lower surface smooth; petioles long, stiff, and erect, smooth except on new growth, which is slightly hairy, purple to pink in color, with heavy purple splash at the base of the leaf blade; roots medium to long, cylindrical, light rose in color; flesh cream to yellow, but dark yellow when baked; fine texture, medium moist, quality good.

CREOLA. (BERMUDA SECTION, SPANISH GROUP.)

Vines long to very long, 8 to 20 feet, vigorous; stems medium to large in size, pink to purple in color, hairy (especially at the nodes); leaves deeply shouldered to nearly lobed, green in color, with purple tinge; petioles light red to purple

in color, dark purple at the summit and at the base of the leaf blade, long and coarse; roots light rose, oblong to fusiform in shape, regular, smooth, no veins, flesh light yellow, but golden yellow when baked; mealy, sweet, fair quality.

RED SPANISH. (RED SPANISH SECTION, SPANISH GROUP.)

Vines moderately large growing, long, 6 to 12 feet; stems dark purple in color, somewhat hairy; leaves deeply shouldered, smooth or with scattered hairs on the midrib and margin of the blade, dark green with purple veins; petioles purple, smooth; roots dark red in color, smooth and fairly regular, long fusiform to cylindrical in shape, medium to large in size, season late; flesh white with a tinge of purple in the center and near the skin. When baked the flesh is grayish white, fairly sweet, moist, and soft in texture.

PURPLE "YAM," OR NIGGER CHOKER. (RED SPANISH SECTION, SPANISH GROUP.)

Vines long, 6 to 15 feet, stems dark purple in color, somewhat hairy; leaves shouldered, entirely smooth or with scattered hairs on the midrib and margin of the blade, dark green with purple veins; petioles nearly smooth, dark purple; roots deep purple in color, smooth and regular, long cylindrical in shape, medium to large; season late; flesh white, often with a tinge of purple beneath the skin and at the center, but dull grayish white when baked; only slightly sweet, very dry and mealy.

DAHOMEY. (RED SPANISH SECTION, SPANISH GROUP.)

Vines medium to long, 6 to 10 feet; stems green tinged with purple, medium coarse, hairy; leaves entire and heart shaped, tinged with purple around the edge and on the veins of the under surface, hairy on the upper surface, smooth to slightly hairy below; petioles long, 6 to 10 inches, slender, purple toward the base and with a deep-purple splash at the base of the leaf blade and the summit of the petiole; roots deep red to purple, long cylindrical; flesh creamy white, but pale yellow when baked; fine in texture, dry, mealy, fairly sweet, only fair quality.

SHANGHAI. (SHANGHAI GROUP.)

Vines large and vigorous, medium to long, 6 to 9 feet; stems green, hairy; leaves shouldered or entire, hairy on the veins above and smooth beneath, green except for a deep purple stain at the base of the blade and the summit of the petiole, the latter otherwise green, hairy; roots white, fairly smooth and regular, without veins, fusiform to long cylindrical, very large; season late. When baked, the flesh is grayish white, only slightly sweet, dry, and mealy; fairly firm in texture.

MINNET "YAM." (SHANGHAI GROUP.)

Vines long, 8 to 16 feet, coarse; stems green, long internodes, hairy; leaves entire and heart shaped, large, hairy on the upper surface, smooth below; petioles long, smooth except at nodes, green with a dark-purple splash at the summit of the petiole and the base of the leaf blade; roots white, fusiform in shape, heavily ribbed or veined; flesh pale yellow, but light yellow when baked; mealy, dry, poor quality.

FLORIDA. (FLORIDA GROUP.)

Vines large, vigorous, medium in length, 4 to 9 feet; stems green in color, nearly smooth; leaves toothed or entire with 6 to 10 low marginal teeth, hairy above (especially on new leaves) and smooth below, green except for a deep-

purple stain at the base of the blade and the summit of the petiole; petiole smooth or nearly so, green except at the upper end; roots light yellow in color with lighter yellow veins, fairly smooth and regular, long fusiform in shape, medium in size; season medium to late; flesh light yellow. When baked, sweet, moist, and soft in texture.

GENERAL GRANT VINELESS. (FLORIDA GROUP.)

Vines medium to large and vigorous, medium in length, 4 to 10 feet; stems green, slightly hairy (especially at the nodes); leaves entire or slightly toothed, hairy above, slightly hairy beneath (especially on the veins), green in color, a deep-purple stain at the juncture of the blade and the petiole; petiole green except at the upper end, nearly smooth; roots light salmon, smooth and regular, short fusiform to long fusiform in shape, medium in size, season medium to early; flesh grayish yellow when baked; sweet, dry, and somewhat mealy; fairly firm in texture.

NANCY HALL. (FLORIDA GROUP.)

Vines medium in length, 4 to 8 feet; stems somewhat hairy, green; leaves toothed or entire with 4 to 10 low marginal teeth, hairy on the upper surface and slightly hairy or smooth beneath, green except for a reddish purple stain at the juncture of the blade and the petiole, the latter slightly hairy, green except at the upper end; roots yellow, tinged more or less with salmon, veined, or smooth and regular, fusiform in shape, medium to large in size; season early; flesh dark yellow, tinged with salmon. When baked, very sweet, moist and soft in texture; good quality. (Pl. VI, figs. 1 and 2.)

WHITE "YAM." (SOUTHERN QUEEN GROUP.)

Vines vigorous in growth, long, 5 to 12 feet; stems dull purple, slightly hairy; leaves shouldered or entire, hairy on the veins above, but otherwise smooth, green; petiole nearly smooth, greenish purple; roots yellowish white, with many low veins, otherwise smooth and regular, fusiform or oblong in shape, medium to very large in size, season medium; flesh light yellow. When baked, sweet, quite dry, and mealy; texture fairly firm.

SOUTHERN QUEEN. (SOUTHERN QUEEN GROUP.)

Vines large and vigorous, long, 6 to 12 feet; stems dull purple, slightly hairy (especially at the nodes and on new growth); leaves shouldered or entire, slightly hairy above, green; petiole nearly smooth, greenish purple. Roots white or light yellow, sometimes very slightly tinged with pink, smooth and regular, few or no veins, fusiform, globular or ovoid in shape, medium to large; season medium; flesh light yellow. When baked, sweet, moist, and soft in texture. (Pl. VI, figs. 3 and 4.)

Ballinger's Pride is a strain of Southern Queen, with roots smaller, longer, fusiform in shape, very smooth.

Catawba White and Catawba Yellow are the same as Southern Queen, but the roots smaller, longer, smooth, and attractive in size and shape.

PUMPKIN "YAM." (PUMPKIN GROUP.)

Vines moderately large growing, long, 6 to 12 feet; stems green, hairy; leaves low, shouldered, hairy only on the upper surface, green; petioles green, hairy; roots yellow, tinged with salmon, mostly irregular with prominent light-

American Varieties of Sweet Potatoes. III.

Fig. 1.—Nancy Hall, one of the best varieties of the moist-fleshed type. Fig. 2.—Foliage of Nancy Hall, mature (above) and immature (below). Fig. 3.—Southern Queen, a heavy yielder of fair quality; known in many sections as the Hayman. Fig. 4.—Young and old foliage of the Southern Queen.

American Varieties of Sweet Potatoes. IV.

Fig. 1.—Pumpkin Yam, a representative of the Pumpkin group. Fig. 2.—Foliage of the Pumpkin Yam, mature (above) and immature (below). Fig. 3.—Dooley, a popular variety and a representative of the Pumpkin group. Fig. 4.—Red Jersey, a member of the Jersey group, largely grown for commercial purposes.

American Varieties of Sweet Potatoes. V.

Fig. 1.—Big-Stem Jersey, one of the leading commercial varieties. Fig. 2.—Foliage of the Big-Stem Jersey, mature (at right) and immature (at left). Fig. 3.—Yellow Jersey, the leading variety in the Jersey section. Fig. 4.—Foliage of Yellow Jersey, fully developed (above) and young leaf (below). Fig. 5.—Gold Skin, a member of the Jersey group; of good quality.

yellow veins, some smooth and regular with few or no veins, fusiform in shape, medium in size, season late; flesh dark orange-yellow. When baked, very sweet, moist, and soft in texture. (Pl. VII, figs. 1 and 2.)

NORTON. (PUMPKIN GROUP.)

Vines moderately large growing, long, 6 to 12 feet; stems hairy, green, or sometimes with a slight purple tinge; leaves shouldered or entire, with four to six low marginal teeth, hairy on the upper surface and to some extent beneath, green or sometimes with a slight purple tinge on the upper surface; petioles green, hairy; roots light salmon with light-yellow veins, smooth and regular, fusiform to slightly cylindrical in shape, medium to large; season late; flesh dark yellow. When baked, very sweet and sugary, moist to very moist, soft and melting in texture.

DOOLEY. (PUMPKIN GROUP.)

Vines long to very long, 10 to 15 feet; stems green, slightly hairy (especially at nodes); leaves shouldered or often entire, green in color, hairy above and smooth beneath; petioles green, slightly hairy; roots large in circumference, short fusiform in shape, yellow to salmon in color; flesh dark orange. When baked, soft and sweet, squashlike. (Pl. VII, fig. 3.)

WHITE GILKE. (PUMPKIN GROUP.)

Vines medium short, 3 to 6 feet, or bushy; stems green, coarse, short internodes, hairy (especially at nodes); leaves entire or heart shaped, slightly hairy above, but smooth on the under surface; petioles green, smooth, or slightly hairy near the nodes; roots white to pale russet yellow, smooth, fusiform in shape; flesh yellow to salmon but a golden yellow when baked; fine in texture, fairly sweet, moist, good quality.

JAPAN BROWN. (RED JERSEY SECTION, JERSEY GROUP.)

Vines long, running 6 to 15 feet; stems green, hairy, coarse, long internodes; leaves toothed or entire with four low marginal teeth, smooth on the upper surface of the leaf, slightly hairy below; petioles long, coarse, hairy, green; roots red, long fusiform or slightly cylindrical; flesh white, but light yellow when baked; mealy, coarse in texture, fair quality; season late.

RED JERSEY. (RED JERSEY SECTION, JERSEY GROUP.)

Vines low and slender in growth, long, 6 to 12 feet; stems green, hairy (especially at the nodes); leaves shouldered, often entire, hairy on the upper surface and smooth beneath, green; petiole green, hairy; roots red in color, fusiform or spindle shaped, smooth and regular or veined to some extent, small to medium in size; season medium; flesh yellow. When baked, fairly sweet, very dry, and mealy; firm in texture. (Pl. VII, fig. 4.)

VINELAND BUSH. (BUSH SECTION, JERSEY GROUP.)

Vines vigorous in growth, very short, 1 to 2½ feet; stems green, hairy, sometimes fasciated; numerous leaves, this character resulting from the very short internodes; leaves shouldered or more often entire, hairy above and smooth beneath, green; petioles green, slightly hairy; roots russet yellow in color, smooth and regular, fusiform to ovoid, not veined, medium in size, season early; flesh yellow. When baked, sweet, dry, and mealy; firm in texture.

BIG-STEM JERSEY. (BIG-STEM JERSEY SECTION, JERSEY GROUP.)

Vines moderately large growing, long, 6 to 12 feet; stems green, hairy; leaves shouldered or entire, hairy above and smooth beneath, green; petiole hairy, green; roots russet yellow in color, smooth and regular, long fusiform in shape, may be veined or smooth, small to large in size, but larger than Yellow Jersey or Red Jersey, season medium to late; flesh yellow. When baked, sweet, dry, and mealy; texture firm. (Pl. VIII, figs. 1 and 2.)

PHILIPILI. (BIG-STEM JERSEY SECTION, JERSEY GROUP.)

Vines vigorous; medium in length, 4 to 8 feet; stems large, green, slightly hairy; leaves entire, hairy above and smooth on lower surface, light green in color; petioles green, slightly hairy at base; roots white or slightly russet yellow in color, flesh white, but pale yellow when baked; dry and mealy; poor quality.

YELLOW JERSEY. (YELLOW JERSEY SECTION, JERSEY GROUP.)

Vines small, slender, long, 6 to 12 feet; stems green, hairy, often fasciated; leaves shouldered or entire, hairy only on the upper surface, green; petioles green, hairy; roots dark russet yellow, long or short, fusiform to globular or ovoid in shape (two types known on the market, one long fusiform and another very short), smooth or veined; small to medium in size; season medium, flesh yellow. When baked, very dry and mealy, fairly sweet; texture quite firm. (Pl. VIII, figs. 3 and 4.)

GOLD SKIN. (YELLOW JERSEY SECTION, JERSEY GROUP.)

Vines medium to long, 6 to 10 feet; slender, hairy (especially at nodes); green in color; leaves shouldered or entire (both forms may be found on the same vine), light green, hairy above, slightly hairy beneath; petioles short, slender, hairy, green, except for slight tinge of purple at the base of the leaf blade; roots dark russet yellow, fusiform in shape, smooth and regular; season medium; flesh salmon, but a dark yellow when baked; medium dry and mealy, very sweet; texture firm. (Pl. VIII, fig. 5.)

CHECK LIST OF NAMES USED IN SWEET-POTATO LITERATURE.

Names appearing in boldface type are recognized varieties; those in italic type are synonyms.

Adams. Synonym of YELLOW STRASBURG.

African Bunch.

African Red (probably same as RED SPANISH).

Alabama.

Alabama Red (probably same as PORTO RICO).

Amarillo.

Archers' Hybrid. Synonym of SOUTHERN QUEEN.

Archias Hybrid (probably same as SOUTHERN QUEEN).

Arizona Prolific. Synonym of FLORIDA.

Arkansas Beauty. Synonym of PIERSON.

Arkansas Hybrid. Synonym of SOUTHERN QUEEN.

Arranca madre.

Bahama or Bahamas (probably same as SOUTHERN QUEEN).

Bahama "yam" (sometimes called Mexican "yam").

Baker. Synonym of TRIUMPH.

Ballinger's Pride. Synonym of SOUTHERN QUEEN.

Barbado. See Barbados.
Barbadoes. See Barbados.
Barbados.
Barbados Seedlings.
Barbascoa.
Bardos (probably same as SOUTHERN QUEEN).
Baydus (sometimes known as Barbadoes).
Belmont.
Benson.
Benson Mammoth (probably same as Benson).
Bermuda (probably same as RED BERMUDA).
Bermuda Red (probably same as RED BERMUDA).
Bermuda Sweet.
Bermuda White.
Big Leaf. Synonym of YELLOW JERSEY.
Big-Leaf Jersey.
Big Stem (probably same as BIG-STEM JERSEY).
Big-Stem Jersey.
Big-Stem Nansemond (probably same as BIG-STEM JERSEY).
Black.
Black Rock.
Black Spanish. Synonym of RED SPANISH.
Blanca.
Blanco.
Bloomer Nansemond (probably same as YELLOW JERSEY).
Boca Sagarto.
Boone Red. See Boone's Red.
Boone's Red.
Boone's White.
Bradley "yam."
Brasiliano (probably same as Brazilian).
Brass Cannon.
Brazilian. Synonym of SOUTHERN QUEEN.
Brazilian "yam" (probably same as Brazilian; sometimes called White Brazilian).
Bronze.
Bronze Spanish. Synonym of YELLOW SPANISH.
Bronze Yellow (probably same as YELLOW SPANISH).
Brown Seedling.
Brujo blanco.
Brujo colorado.
Brujo morado.
Buckskin (probably same as SOUTHERN QUEEN).
Buck "yam."
Bunch Candy "yam."
Bunch Dooley (probably same as DOOLEY).
Bunch "yam." Synonym of BUNCH CANDY "YAM."
Busby "yam."
Bush "yam."
Caddle (probably same as SOUTHERN QUEEN).
Calabaza.
California. Synonym of SHANGHAI.
California Golden. Synonym of PIERSON.
California "yam." Synonym of SOUTHERN QUEEN.
Camaguez.
Camarete.
Camarioca.
Camote Silbestre.
Campanilla.
Canal.
Candela.
Carolina.
Carolina Extra Early (probably same as Extra Early Carolina).
Carolina "yam."
Caroline Lee. Synonym of SOUTHERN QUEEN.
Catawba White. Synonym of SOUTHERN QUEEN.
Catawba "yam" (probably same as SOUTHERN QUEEN).
Catawba Yellow. Synonym of SOUTHERN QUEEN.
Cavitt's Earliest.
Cedarville. Synonym of YELLOW JERSEY.
Centauro amarillo.
Centauro colorado.
Chazal.
Chesboro.
Chinese 30 Days.
Chinco blanco.
Choker (sometimes called Orleans Red).
Ciclon.
Cienfuegos.
Cinco dedos.
Cluster "yam."

Colman "yam."
Columbia Yellow.
Common Louisiana "yam" (sometimes called Georgia "yam").
Common Red.
Common "yam." Synonym of SOUTHERN QUEEN.
Connelly's Early Red. Synonym of RED JERSEY.
Cooney.
Creola.
Creole (sometimes called Sugar "yam").
Cuba.
Cuba "yam." Synonym of RED BERMUDA.
Cuban. Synonym of SOUTHERN QUEEN.
Cuban Queen (probably same as SOUTHERN QUEEN).
Cuban "yam."
Cullman Cream "yam" (probably same as SOUTHERN QUEEN).
Curtis.
Dade County.
Dahomey.
Davis' Enormous.
Davis' Golden Beauty (probably same as PORTO RICO).
Delaware (Jersey group, probably GOLD SKIN).
Dhamake White.
Disciplinado.
Dog River.
Dooley.
Dooley "yam" (probably same as DOOLEY).
Dunton's Early. Synonym of PIERSON.
Dunton's Improved. Synonym of BELMONT.
Early Bloomer Nansemond. Synonym of YELLOW JERSEY.
Early Bunch "yam" (probably strain of Bunch "yam").
Early California (probably strain of California).
Early Carolina. Synonym of YELLOW JERSEY.
Early Caroline (probably strain of YELLOW JERSEY).
Early General Grant. Synonym of PIERSON.
Early Golden. Synonym of SHANGHAI.
Early Golden "yam."
Early Jersey (probably same as YELLOW JERSEY).
Early Light Jersey (probably same as YELLOW JERSEY).
Early Nansemond (probably same as YELLOW JERSEY).
Early Peabody (probably strain of PEABODY.
Early Red.
Early Red Carolina. Synonym of RED JERSEY.
Early Rivers.
Early Peabody (probably strain of TRIUMPH).
Early Yellow. Synonym of PUMPKIN "YAM."
Early Yellow Bunch.
Early Yellow Carolina (probably same as YELLOW JERSEY).
Early Yellow Jersey. Synonym of YELLOW JERSEY.
Early Yellow Nansemond (probably same as YELLOW JERSEY).
Early York.
Eclipse Sugar "yam."
Ely.
Enano.
Enormous.
Extra Early Accomac.
Extra Early Carolina.
Extra Early Caroline (probably same as YELLOW JERSEY).
Extra Early Golden. Synonym of YELLOW STRASBURG.
Extra Early Red Caroline (probably same as RED JERSEY).
Extra Red Carolina (same as RED JERSEY).
Familia.
Fire Brass.
Florida.
Florida (sometimes applied to BIG-STEM JERSEY).
Florida Bunch.
Florida Bunch "yam" (probably same as SOUTHERN QUEEN).
Florida "yam." See Florida.
Forked-Leaf Pumpkin (probably same as PUMPKIN "YAM").
Forty in a Hill.
Fullerton Yellow "yam."
Furbelow Yellow "yam."

General Grant (probably same as SOUTHERN QUEEN).
General Grant Vineless.
Georgia. Synonym of BELMONT.
Georgia Buck (probably same as GEORGIA BUCK "yam").
Georgia Buck "yam." Synonym of VINELAND BUSH.
Georgia Sugar "yam."
Georgia "yam" (sometimes called common Louisiana "yam.").
Gold Coin. Synonym of PIERSON.
Gold Coin Bunch "yam" (probably same as BUNCH CANDY "YAM").
Gold Skin.
Golden Beauty. Synonym of PORTO RICO.
Golden Coin (probably same as SOUTHERN QUEEN).
Golden Queen.
Golden Skin. Synonym of PIERSON.
Golden Strassburg (probably same as YELLOW STRASBURG).
Governor.
Gros Grandia.
Guinero.
Hache.
Haiti "yam" (sometimes called MUSGROVE).
Hall. See NANCY HALL.
Halomai "yam."
Halonaipu.
Hamburg. Synonym of SOUTHERN QUEEN.
Hannover. See Hanover.
Hanover. Synonym of SOUTHERN QUEEN.
Hanover (sometimes called ROYAL OF HANOVER).
Hanover "yam." See HANOVER.
Harman (sometimes called WHITE "YAM").
Hayman. Synonym of SOUTHERN QUEEN.
Hayti (probably of the Spanish group).
Hayti Spanish (probably of the Spanish group).
Heckler.
Heckler "yam."
Hen and Chickens.
Hornero.
Horton "yam."
Huamoa.
Huffs.
Hunt's Red.
Ihumai.
Improved Big Stem. Synonym of BIG-STEM JERSEY.
Improved Big-Stem Jersey. See BIG-STEM JERSEY.
Improved Dooley "yam." See DOOLEY.
Improved Providence. See PROVIDENCE.
India Red.
Indian Red.
Isla de Pinos.
Japan Brown.
Japanese "yam" (probably of the Belmont group).
Java No. 1. (Introductions.)
Java No. 2. (Introductions.)
Java No. 3. (Introductions.)
Java No. 4. (Introductions.)
Java No. 5. (Introductions.)
Jersey (probably same as YELLOW JERSEY).
Jersey Red (probably same as RED JERSEY).
Jersey Sweet (probably of the Jersey group—YELLOW JERSEY).
Jersey Yellow (probably same as YELLOW JERSEY).
Jerusalem.
Jerusalem "yam."
Jewell "yam."
Jiguani.
John Burnet.
Johnson's Bahama. Synonym of SOUTHERN QUEEN.
Kala.
Kapo.
Kauaheahe.
Kawelo.
Kelly's. Synonym of YELLOW JERSEY.
Kentucky White. Synonym of SOUTHERN QUEEN.
Key West.
Key West "yam."
Key West "yam" (sometimes applied to PORTO RICO).
Koali.
Laiakona.
Lexington "yam."
Light Early Red.
Little Bunch.

Little-Stem Jersey (probably same as YELLOW JERSEY).
Louisiana.
Louisiana "yam."
McCoy. Synonym of SOUTHERN QUEEN.
McCoy's Sweet. Synonym of YELLOW JERSEY.
McDonald.
Maleta.
Mamey.
Mameya.
Mameyana.
Mameyita.
Mani.
Mani blanco.
Mani colorado.
Mani morado.
Manila.
Manila colorado.
Marada.
Martinica blanco.
Martinica morado.
Martinico.
Matejita.
Matojito.
Matojo.
MERCED SWEET (same as JERSEY SWEET).
Mexican (sometimes called BAHAMA "YAM").
Miami.
Miles "yam." Synonym of SOUTHERN QUEEN.
Minnet "yam."
Minnie White.
Minute "yam."
Miseria.
Mississippi Yellow (probably same as YELLOW JERSEY.
Molly Malone.
Mono Negro.
Morado.
Morning Glory.
Morris Sweet Seed.
Muffard.
Muffard "yam."
Mulato.
Mullihan. Synonym of NANCY HALL.
Murray.
Murray Extra Early.
Murrey's Extra Early.
Murry's Extra Early.
Muscatine.
Musgrove (sometimes called HAITI "YAM").
Myers' Early.
Myers' "yam."
Nancy Hall.
Nansemond. Synonym of YELLOW JERSEY.
Nansemond Improved (probably same as YELLOW JERSEY.
Nansemond Red (probably same as RED JERSEY.
Nansemond White.
Negrito.
Negro Choker (probably same as NIGGER CHOKER).
Negro Killer (probably same as NIGGER CHOKER).
Newfoundland.
New Jersey (probably same as YELLOW JERSEY.
New Jersey Nansemond (probably same as YELLOW JERSEY.).
New Nansemond (probably same as YELLOW JERSEY).
Nigger Choker. Synonym of PURPLE "YAM."
Nigger Killer (probably same as NIGGER CHOKER).
Nina.
North Carolina "yam."
Northern Yellow.
Norton.
Norton "yam" (probably same as NORTON).
Notch-Leaf Bunch "yam."
Nueva Gerona.
Oebi Hitam.
Oebi Kang Kong.
Oebi Radjit.
Old Maurice.
Old-Time "yam."
Orange.
Oriente.
Orleans Red (sometimes called CHOKER).
Orum.
Padisha.
Padishah.
Pancho.
Pancho del Sol.
Pan con Vino.
Papa.
Papa blanco.
Paragon.
Patasaw "yam."

Pattusal "yam."
Peabody.
Pearson (probably same as PIERSON).
Pepper's Choice.
Peruvian.
Peruvian "yam."
Philipili.
Phillipin "yam" (sometimes called Early Yellow Bunch).
Picadito.
Pierson.
Pikonui.
Pilipili.
Pimento (sometimes called YELLOW PIMENTO).
Poland.
Polo. Synonym of SOUTHERN QUEEN.
Pool's "yam."
Poor Land (probably same as PORELAND).
Poplar Spanish (probably same as POPULAR ROOT SPANISH).
Popular Root (sometimes called SOUTHERN QUEEN).
Popular Root Spanish.
Poreland. Synonym of RED BERMUDA.
Porto Rico.
Porto Viejo.
Pride of Kansas.
Prolific. Synonym of BUNCH CANDY "YAM."
Providence. Synonym of FLORIDA.
Providential.
Pu.
Pumpkin.
Pumpkin Early Yellow "yam."
Pumpkin "yam."
Purple "yam."
Queen.
Queen of the South (probably same as SOUTHERN QUEEN).
Queen of the West.
Rayo.
Red Beans.
Red Bermuda.
Red Brazil.
Red Brazilian.
Red Jersey.
Red Nancemond (probably same as RED JERSEY).
Red Nansemond. Synonym of RED JERSEY.
Red Nose. Synonym of YELLOW JERSEY.
Red Providence.
Red Sealy.
Red-skinned Yellow "yam."
Red Spanish.
Red "Yam."
Redding.
Relampago.
Rockport.
Roosevelt.
Rositas.
Royal Sweet Potato of Hanover. See Hanover.
Running Dooley (probably same as DOOLEY).
Sabanilla blanco.
Sabanilla colorado.
Sadies Prolific.
St. Domingo.
San Domingo (sometimes called WHITE SAN DOMINGO).
San Fernando.
San Juan.
San Pedro blanco.
San Pedro colorado.
San Roque.
Santa Maria.
Santa Rita.
Santiago.
Santiaguero.
Sapotillo.
Shaker Yellow.
Shanghai (sometimes called CALIFORNIA).
Short Vine Yellow "yam."
Sopa en vino.
Southern Nansemond (probably same as YELLOW JERSEY).
Southern Queen.
Southern Red.
Southern Red "yam."
Southern "yam."
Southern Yellow.
Southern Yellow "yam."
Spanish.
Spanish Bunch.
Spanish Poplar.
Spanish Poplar Root.
Spanish Red (probably same as RED SPANISH).
Spanish White.

Spanish "yam." Synonym of PUMPKIN "YAM."
Split Leaf (sometimes known as Georgia "yam").
Strasboury.
Strasburg.
Strassberg.
Strassburg.
Strousburg.
Sugar.
Sugar "yam."
Sulla.
Tennessee.
Tennessee Notchleaf (sometimes called YELLOW "YAM").
Tennessee Notched Leaf.
Tennessee "yam."
Texas "yam."
Thegamia Red.
Thegamia White.
Thompson's Favorite.
Ticotea.
Tolman Spanish.
Tornasol.
Trinidadian No. 1.
Trinidadian No. 2.
Triumph.
True Brass.
True Parson Prince.
Tuna.
Up River. Synonym of YELLOW JERSEY.
Up Rivers (probably same as YELLOW JERSEY).
Vaca.
Van Ness Red.
Van Nest Red. Synonym of RED JERSEY.
Vestal's Newark. Synonym of SOUTHERN QUEEN.
Vestal's New Arkansas Yellow "yam."
Vincetoman "yam."
Vincentonia.
Vineland Bunch.
Vineland Bunch "yam."
Vineland Bush.
Vineland Sweets.
Vineless. Synonym of BUNCH CANDY "YAM."
Vineless Beach.
Vineless Bunch.
Vineless Bunch Nansemond (probably same as VINELAND BUNCH).
Vineless Bunch "yam."
Vineless Pumpkin "yam."
Vineless "yam."
Vinerlonian.
Vino tinto.
Violette Blanche.
Violette Rouge.
Virginia Nansemond.
Virginia Red Nose.
Vuelta amajo.
Vuelta arriba.
Vuelta bajero.
West India "yam."
White Barbadoes.
White Belmont. Synonym of WHITE "YAM."
White Bermuda.
White Brazilian (sometimes called BRAZILIAN "YAM").
White California.
White Columbia.
White Gilk.
White Gilke.
White Gilkes.
White Nansemond (sometimes called ARKANSAS BEAUTY).
White Providence.
White St. Domingo (sometimes called SAN DOMINGO).
White Sealy.
White Seedling.
White Skinner.
White Spanish.
White Vineless.
White West India.
White "yam."
Willets' Red Skin.
"Yams" (sometimes called SOUTHERN QUEEN).
Yellow (sometimes called YELLOW "YAM").
Yellow Barbadoes.
Yellow Bean.
Yellow Belmont. Synonym of YELLOW "YAM."
Yellow Bermuda.
Yellow Buckskin.
Yellow Columbia.
Yellow Jersey.
Yellow Mauritius.
Yellow Nancemond (probably same as YELLOW JERSEY).
Yellow Nansemond. Synonym of YELLOW JERSEY.

Yellow Pimento (sometimes called PIMENTO).
Yellow Providence.
Yellow Red. Synonym of RED BERMUDA.
Yellow Rind.
Yellow Spanish.
Yellow Strasburg.
Yellow Straussberg. See YELLOW STRASBURG.
Yellow Sugar.
Yellow Trinidadian.
Yellow "yam."
Yema de huevo.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 1022

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WM. A. TAYLOR, Chief

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RELATION OF INITIAL TEMPERATURE TO PRESSURE, VACUUM, AND TEMPERATURE CHANGES IN THE CONTAINER DURING CANNING OPERATIONS.

By C. A. Magoon and C. W. Culpepper,

Office of Horticultural and Pomological Investigations.

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CANNING PROBLEMS.

If canned foods of uniform quality are to be produced, the various canning operations must be placed upon a sound scientific basis and the methods which are employed, so far as the nature of the food substance will permit, must be carefully standardized. The situation calls for the elimination of the element of chance and the abandonment of "rule-of-thumb" practices. It is equally important that those factors which affect the cooking or processing of the food after the can is sealed should be thoroughly understood. To throw further light upon the matter of initial temperatures and their bearing upon pressures, vacuums, and temperature changes during and following the processing period, the present work was undertaken, and it is hoped that the data presented herewith will contribute to the solution of some of the canning problems.

REVIEW OF THE LITERATURE.

In an earlier paper the writers (8)[1] presented the results of preliminary studies upon the fundamental factors affecting temperature

[1] Serial numbers in parentheses refer to "Literature cited" at the end of this bulletin.

changes in foods during canning, but a detailed consideration of the important influence which initial temperatures have upon the form of the heat-penetration curves and their bearing upon sterilization processes was reserved until initial temperatures could be taken up in their proper relations with exhaust, pressure, and vacuum.

Since the above-mentioned paper was submitted for publication two further contributions have been made. The first of these, by Thompson (9), enters into a discussion of the theoretical application of physical laws to canning procedures. In addition to the consideration of the general phases of the subject and a study of the diffusivity constant "K" dealt with in his original paper, this author gives valuable formulas for calculating the approximate time-temperature curves for cans of food when processed at different retort temperatures, other factors being the same, and also for calculating the curves for different sizes of cans when processed under like conditions.

Thompson's study of the time-temperature curves for cooling, however, suggests that such curves might be calculated directly from the heating curves, inasmuch as reversing the temperature conditions of the water bath from hot to cold should result in a curve of the same form as the heating curve. That this can hardly be the case with foods will readily be seen. The viscosity of the liquor varies with the temperature. Except where heat brings about a change in the colloidal substances, the heating curve is always a record of a change from a more to a less viscous condition, while in cooling, without exception, the change is from a less to a more viscous condition. The curves will not be the same, as in this case the final portion of the heating curve will be steeper than the corresponding part of the cooling curve. Furthermore, during processing permanent physical changes which alter greatly the rate of heat transfer within the container commonly occur in food substances; hence, even the rough approximation of the real cooling curve by calculating from the heating curve would be difficult, if not impossible. While the differences between the heating and the cooling curves may be negligible from a practical standpoint in some cases, in others they are of very considerable importance. An actual experimental cooling curve would seem to the writers to be the safest way to determine temperature changes during cooling.

In a more detailed and comprehensive manner Bigelow and his collaborators (3) have studied the time-temperature relations of foods during canning. These workers, by the use of a specially constructed thermoelectric apparatus, have carried on extensive investigations upon a wide variety of canned-food materials and have made important contributions to the knowledge upon this subject. In addition to the consideration of both theoretical and practical matters

involved in work of this sort, use has been made of numerous experimental curves, tables, and formulas, which make the work of much value.

Especially useful are the formulas given for calculating from a previously determined curve the time-temperature curves for cans of food having any initial temperature; for calculating curves for cans processed at any temperature from a curve for a can with a known processing temperature; and for calculating curves for a container of any size from an experimental curve determined for a can of known size.

Few cooling curves are given. The statement is made, however, that the temperature will descend during the cooling operation by exactly the same curve that is followed during the processing. What has been said upon this matter in connection with the review of Thompson's article above applies equally here.

Since certain matters discussed in these papers bear directly upon the work herein reported, more detailed reference will be made to them from time to time in the body of this bulletin.

The necessity of properly exhausting cans of food material either by short heating, by filling in the material while hot, or by mechanically removing the air in the can before the final sealing, has long been recognized. It was early believed that the partial vacuum thus formed was largely responsible for the keeping of the food. Later when it was found that food spoilage was due to the activities of microorganisms this idea was abandoned, though the practice of exhausting was continued for other reasons. More recently the work of Weinzirl (10) has focused attention upon the question whether after all the vacuum may not be largely responsible for the keeping of many of our canned foods.

The relation of exhaust and vacuum to swells and springers in canned foods was clearly set forth by Bigelow (1) in 1914. The following year Bitting (4) called attention to the effect which the vacuum has upon the amount of dissolved tin in canned foods and pointed out how the action of the food material on the metal of the container may affect the vacuum.

In 1916 the same author (5) entered into a more detailed consideration of the subject of exhaust and vacuum. Some of the reasons given for exhausting were as follows:

(1) To draw in the ends of the cans, thus giving an index to the condition of the contents.

(2) To minimize the action of the contents upon the container.

(3) To prevent overfilling.

(4) To prevent unnecessary strains on cans.

(5) To produce a desirable effect upon the product itself.

Figures were given for the vacuum produced by heat exhaustion in No. 2½ cans sealed at different temperatures. Tables were given showing the effect of the fill of the can on vacuum, as well as tables showing the amount of vacuum with different sealing temperatures. The relative merits of heat exhaust and mechanical exhaust were discussed, the relation of exhaust and head space to erosions and perforations was emphasized, and other factors influencing vacuum were enumerated.

In 1917 Bitting and Bitting (7) reported upon further studies along this line. Attention was called to the pressure developed in tin cans during processing, which showed very considerable divergence from the pressure calculated from physical laws. These investigators stated also that gases incorporated in the tissues of fruits and in cold-storage products cause a decided increase above normal pressure in processing.

Tables showing the absolute pressure of saturated steam at various temperatures and also tables showing the expansion of water were given by Bitting and Bitting. They discussed also the pressures developed when cans were filled with different quantities of hot and of cold water.

The possible relation of exhaust and vacuum to the black discoloration of corn was pointed out more recently by Bigelow (2).

The material presented in these papers is rich in suggestion and of much practical importance. Through them the practice of exhausting is placed upon a sound scientific basis.

In the present work the writers have found it necessary for their purposes to cover in an experimental way some of the same ground included in the above-mentioned investigations. At the points of contact between the work of the earlier investigators and that herein reported more detailed references will be made.

NEED FOR STUDY OF INITIAL TEMPERATURE IN ITS RELATION TO PRESSURE AND VACUUM.

The problem always before the canner is how to get the best quality in the finished product. In striving for the best quality many things are to be considered, such as selection of the best varieties, prompt transfer from the field to the place of canning, and proper treatment previous to filling the can. But the thing of greatest importance is to secure the proper condition in the can so as to protect the food against microorganisms and at the same time develop and preserve the desirable flavors in the product. A thorough knowledge of conditions in the can, therefore, will facilitate the choosing of the best procedure.

The chief altering factor in the can is the temperature. Proper temperature maintained for a length of time sufficient to prevent

the subsequent development of the organisms causing spoilage must be provided for first, but for the sake of the quality it should not be prolonged beyond the time essential to insure the keeping of the product and the safety of the food for human consumption; in other words, the temperature factor must be under careful control.

Another factor greatly affecting the quality of the finished product is the amount of air present in the can. The presence of air may result in enormous strains on cans, causing leakage and loss, in the discoloration of the product, and in increased activity of the food material upon the metal of the container. In other ways also it has a direct bearing upon the quality of the product. It is evident, therefore, that this factor likewise must be kept under control. This may be accomplished by some method of exhaust.

Inasmuch as under present conditions the exhaust is effected primarily by the use of heat and inasmuch as the initial temperature of the material in the can affects the time-temperature curves, it is apparent that in determining the proper temperature and duration of the processing period the exhaust must be carefully considered. In other words, the exhausting procedure must be standardized before the processing temperatures can be prescribed and the processing periods determined.

As is well known, exhausting may be accomplished in three ways: First, by filling the cans with the material, after it has been heated to the desired temperature, as with corn, sweet potatoes, etc.; second, by subjecting the cans of material to a preliminary heating before sealing; and, third, by mechanically removing the air, or sealing in a vacuum chamber.

Whichever method is used, it is especially important that so far as possible uniform temperatures shall exist throughout the entire mass in the can and that processing shall begin at the earliest possible moment, preferably at once. As has been shown graphically by Bigelow and his collaborators (3, p. 63), unless this is the case the time-temperature curve at the center of the can may actually fall during the first part of the processing period and thus make impossible an accurate knowledge of the temperature changes taking place during the processing period. Under such conditions careful standardization is out of the question.

With these things in mind and with a view to gaining a definite knowledge of the temperature changes taking place under carefully controlled conditions as regards the time-temperature relation in food materials sealed at different temperatures and the relation of these matters to pressures developed and vacuum obtained, the present work was undertaken.

METHODS AND APPARATUS.

DETERMINATION OF PRESSURE.

In the pressure and vacuum studies, preliminary experiments soon showed that the pressure and vacuum gauges commonly used were too coarse and inaccurate for careful work. Because of their mechanical construction they are always open to the danger of becoming weakened, which makes frequent standardization necessary. They also seem abnormally sensitive to barometric pressure, for which corrections are difficult. Their use in this work was therefore abandoned except in certain rough tests mentioned below, and in their place a special mercury manometer was substituted. Figure 1 illustrates the manometer.

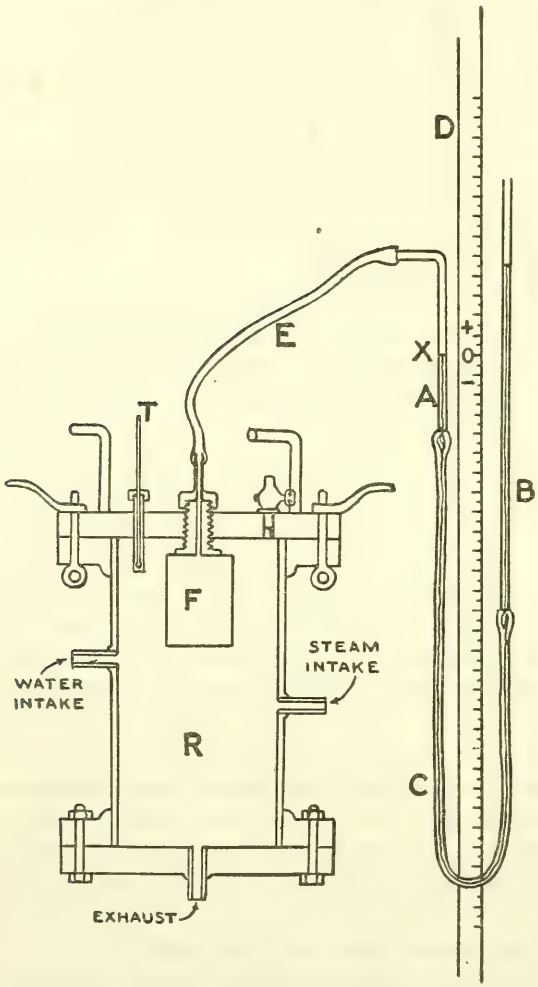

FIG. 1.—The manometer used in the pressure-vacuum tests. *A*, Fixed glass arm of the manometer; *B*, movable glass arm; *C*, flexible rubber tube wound with copper wire connecting glass arms *A* and *B*; *D*, scale, graduated in centimeters or inches; *E*, flexible rubber tube wound with copper wire connecting manometer with the can-sealing device; *F*, test can; *R*, steam retort; *T*, thermometer; 0, zero mark on the graduated scale; *X*, mark on glass arm *A* corresponding with the zero mark on the scale *D*, at which the mercury column in *A* is held constant. The plus and minus signs on the scale indicate the portions of the scale above and below the zero mark, respectively.

This manometer consists of two glass arms, *A* and *B*, which are connected by a flexible tube (*C*) of rubber pressure tubing reinforced with closely wound copper wire to minimize expansion. A scale *D*, so graduated as to allow readings in both directions from 0, is so placed that the zero mark stands at x of the glass arm *A*, which represents the constant level of the mercury in that arm. The flexible tube *E*, which is identical in structure with *C*, connects with an air-tight junction

glass arm A with the test can F, located in the retort R, as described for temperature tests in United States Department of Agriculture Bulletin No. 956, entitled "A Study of the Factors Affecting Temperature Changes in the Container during the Canning of Fruit and Vegetables." Retort temperature is controlled by the thermometer T. During the test the pressure which causes the level of the mercury to fall in arm A is compensated for by raising arm B, and the mercury in arm A is therefore maintained at the constant level x, corresponding to the zero graduation on scale D. The volume of gas in the retort side of the apparatus is kept constant and the pressure in centimeters or inches, as desired, read directly from the + portion of the scale. Similarly, the vacuum is read by lowering arm B, to compensate for the rise of mercury in A, and the vacuum is read directly from the — portion of the scale. The can being attached to the cover of the small retort, the flexible tube E allows the prompt removal of the test can from the retort in a few seconds and the cooling of the can either in air or in water, as desired.

This apparatus is very sensitive to slight changes in pressure, demonstrates very quickly any leaks present, and has proved very satisfactory. By means of this apparatus the writers have been able to conduct tests upon all classes of substances in various quantities with different sizes of cans at any initial temperature and retort temperature desired.

DETERMINATION OF TEMPERATURE.

Data upon temperature changes were obtained in the same manner as described in United States Department of Agriculture Bulletin No. 956, and all temperatures, both of retort and can, were made with special carefully standardized mercury thermometers.

In the paper previously reviewed, Bigelow and his collaborators object to the use of a mercury thermometer for this purpose, on the ground that heat is conducted down the stem to the mercury bulb. According to Smithsonian conductivity tables, the conductivity of glass and water is practically the same. It is evident, therefore, that the conductivity of glass is about the same or slightly less than the minimum for any food substance. Since, also, the distance from the ends of the can to the center is greater than the radius, the heat should reach the mercury bulb through the food from the side before it could be conducted down the stem of the thermometer. In the thermocouple used by Bigelow and his collaborators, which is inserted into the can in the same way as the thermometer, the thermal junction is soldered to the end of a bare copper tube, which in turn is soldered to the end of a brass tube, the external portion of which during processing is subjected to the full temperature of the retort, which allows of rapid conduction of heat into the can. With the

conductivity of copper at about 1.0, of brass at about 0.25, and of glass at 0.002, the chances of error from heat conduction are hundreds of times greater with this thermocouple than with the thermometer.

It must be borne in mind that in experimental work with canned foods small inaccuracies are of minor importance. Because of the differences in the consistency of the material, of difficulty in preparing uniform packs, of difficulty in adjusting closely the retort temperatures throughout the entire process, and of other factors, it is practically impossible to check time-temperature curves closer than 0.5° C., and it is doubtful whether a difference of 0.5° C., or perhaps even more with materials of this kind, is of any practical significance.

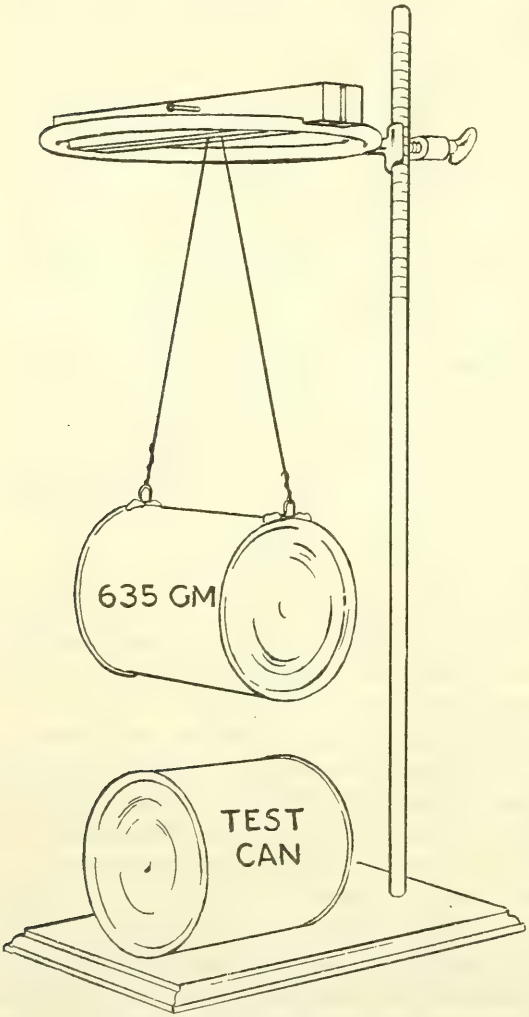

FIG. 2.—Apparatus used in the concussion tests.

PRACTICAL VACUUM TESTS.

In an attempt to determine the optimum temperature for sealing, cans of various materials were prepared in lots which were sealed at the temperatures of 20°, 50°, 60°, 70°, 80°, 90°, and 100° C., respectively. In some cases, instead of this procedure, the cans were exhausted for two, four, or six minutes and then sealed. In each case the lots were divided and one half were tested for vacuum with a common Young's vacuum gauge, and the remainder were subjected to concussion tests to learn to what extent the vacuum affects the denting and collapsing of cans in ordinary handling.

CONCUSSION TESTS.

The apparatus illustrated in figure 2 was employed in the concussion tests.

This apparatus consists merely of an ordinary laboratory ring-stand support, the standard of which is graduated in centimeters. The adjustable ring supports a wooden block, which is sawed lengthwise to allow the entrance of a fine copper wire attached to a weighted can. A metal pin in this block holds the wire until ready for release. The test can is placed on the platform at right angles, with the weighted can suspended above in such a way that the weight in falling strikes it midway between the ends. The weight is raised to the desired height by adjusting the ring. The weight is prepared by cutting a hole in the side of an ordinary No. 2 can with both ends crimped on and running into it the required quantity of molten lead while the can is lying on its side. This, in addition to furnishing the required weight, lends rigidity to the can and prevents its denting. In these tests the over-all weight of the can was 635 grams, which corresponds closely to the weight of an ordinary No. 2 can of food.

With this arrangement the can of food to be tested may be subjected to the most rigid treatment and will thus give an index to its relative resistance to handling when subjected to variable exhausts.

CONTAINERS.

The containers used in these tests were the standard packers' cans. Because of their adaptability for ready attachment to the other apparatus the hole-and-cap type, with ends mechanically crimped on, was employed for the most part, though the cans used for the concussion and rough vacuum tests described later were of the open-top type. The great difficulty in finding cans with air-tight seams made it necessary in all cases where great accuracy was required to solder all ends over the seam before making a test. In the canning tests covered by this and other studies during the last season, as high as 18 to 20 per cent of the cans have been found to show visible leaks at the factory ends when they were taken from the retort. It is to be expected that small leaks will show up when great pressures are developed, but certainly visible leaks should not appear to this extent where common canning practices are employed, as was true in these cases.

THEORETICAL PRESSURES AND VACUUMS.

The development of pressure and the formation of vacuum follow the well-known physical laws for gases and saturated vapors with changes of temperature. A consideration of the theoretical

values as affecting canning operations is therefore important for the present work; and while it is not possible to calculate by formulas the actual results which will be obtained in practice, because of other variable factors, the theoretical pressures and vacuums falling within the range of the present experiments serve as a background for the work and as a guide in the interpretation of the experimental results.

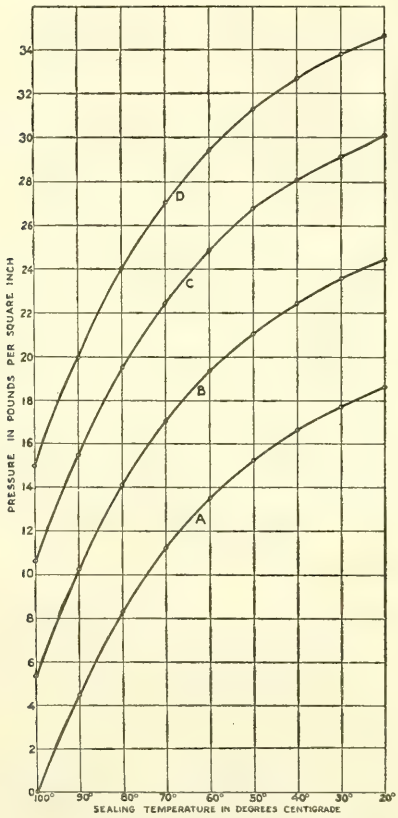

FIG. 3.—Theoretical maximum-pressure curves for a nonexpansible can containing air and sufficient water to give saturation, when sealed at different uniform temperatures and processed in the retort at 100°, 109°, 116°, and 121° C. Calculations are made on the basis of mean barometric pressure. Curve for can processed: *A*, At 100° C.; *B*, at 109° C.; *C*, at 116° C.; *D*, at 121° C.

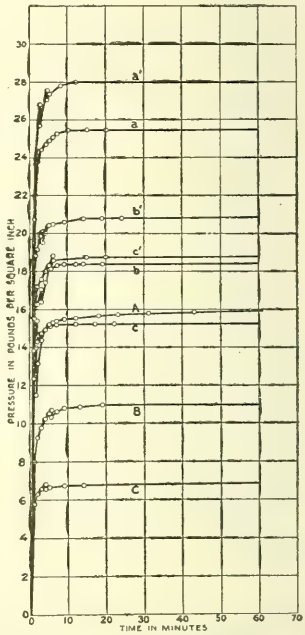

FIG. 4.—Experimental time-pressure curves for No. 2 cans containing 550 c. c. of distilled water sealed at uniform temperatures and processed for 1 hour. Curve for can sealed: *A*, At 20° C. and processed at 100° C.; *a*, at 20° C. and processed at 116° C.; *a'*, at 20° C. and processed at 121° C.; *B*, at 70° C. and processed at 100° C.; *b*, at 70° C. and processed at 116° C.; *b'*, at 70° C. and processed at 121° C.; *C*, at 80° C. and processed at 100° C.; *c*, at 80° C. and processed at 116° C.; *c'*, at 80° C. and processed at 121° C.

Theoretical pressure curves.—In figure 3 are shown the theoretical maximum-pressure curves for a nonexpansible can containing air and a sufficient quantity of water to give saturation, when

sealed at various temperatures and processed at 100°, 109°, 116°, and 121° C. These are calculated for the mean barometric pressure.

These curves show how relatively great pressures are developed when containers are sealed at the low temperatures and bring out clearly the fact that when the sealing temperature is increased the pressures are not reduced in the same proportion, but fall off with increasing rapidity as the sealing temperature of 100° C. is approached. They also serve as a general guide in the selection of the most desirable sealing temperatures.

Relation of time to pressure changes.—The relation of time to the pressure changes during processing is illustrated in figure 4, which shows the time-pressure curves obtained for the No. 2 can containing 550 c. c. of water.

Attention is directed especially to the steepness of the curves during the first minute of the processing and to the fact that the pressure shortly reaches an equilibrium. The close correlation of the pressure changes and time-temperature changes in the can is clearly shown. The comparison of the form of these curves with the curves for the various food materials shown later will be found of much interest. Sharp breaks in the curves, as in the others which follow, show where the sudden bulging of the cans occurred.

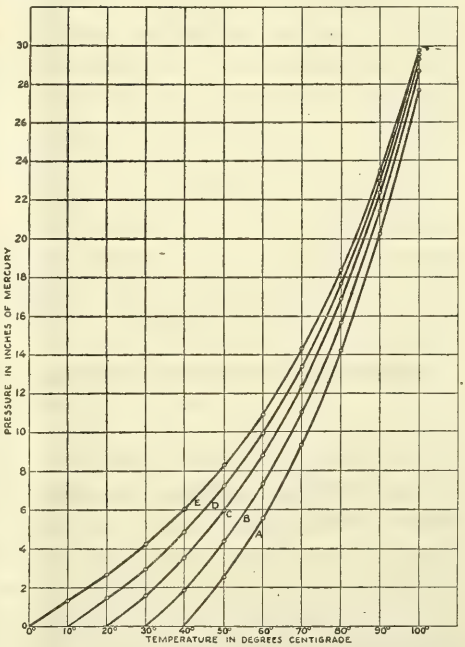

FIG. 5.—Theoretical vacuum curves for a noncontractile can containing air and sufficient water to give saturation when sealed at different uniform temperatures and read at 0°, 10°, 20°, 30°, and 40° C. Calculations are based upon mean barometric pressure. Curve for readings made: *A*, At 40° C.; *B*, at 30° C.; *C*, at 20° C.; *D*, at 10° C.; *E*, at 0° C.

Theoretical vacuum curves.—Of equal, if not of greater importance, is the matter of vacuum obtained as the result of various canning operations. Here, again, theoretical figures serve as a background for experimental work and furnish information of much practical value. Figure 5 shows the theoretical vacuum curves for a noncontractile receptacle containing air and saturated vapor when sealed at various temperatures and cooled to the uniform temperature of 0°, 10°, 20°, 30°, and 40° C. These are calculated on the basis of mean barometric pressure.

These curves show how, as the sealing temperature is increased, the pressure is developed and bring out the fact that as the cooling temperature approaches 100° C. the vacuum increases progressively. They also show how the vacuum is affected by the temperature to which it is cooled. For example, a can sealed at 70° C. and subsequently cooled to 20° C. should give a theoretical vacuum of about 12.3 inches; if cooled to 30° C., a vacuum of about 10.9 inches; or if cooled to 0° C., a vacuum of 14.3 inches. They likewise illustrate how cans of food having a low vacuum, although sound and healthful, may, when stored in warm places or shipped to hot climates, show no vacuum at all, or possibly in some cases even develop springers. For instance, a can of food which at 10° C. showed approximately 3 inches of vacuum when held at 30° C. would have no vacuum at all. Similarly, though of less importance, it shows how cans having relatively high vacuums would suffer more in shipment and handling in low temperatures, due to the denting or collapsing of the cans. One may, therefore, gain from these curves an idea of the approximate vacuums to be expected under conditions within the range of canning operations.

EXPERIMENTS WITH DISTILLED WATER FOR COMPARISON.

As is well known in canning, theoretical values are practically never obtained because numerous variable factors enter in which influence practical results. In order to discover what and how great these variable factors are, to learn how closely the theoretical and the practical results agree, and to obtain information which would serve as a base line for the comparison of various food materials when canned in different ways, preliminary pressure and vacuum experiments were made with water, using No. 2 and No. 3 tin cans. The experiments were conducted as follows: The test cans were prepared by carefully soldering all seams and joints to insure against leakage; the required quantity of water was measured in; the can was placed in the retort in the manner illustrated and held under carefully controlled conditions until both can and contents came to the desired uniform temperature throughout; the can was then sealed. The barometric reading at the time of sealing was noted and the pressure determinations immediately performed. In this way tests were made using various quantities of water, sealed at different temperatures, and processed in the retort at 100°, 109°, 116°, and 121° C.

PRESSURE STUDIES.

Pressure readings obtained in tests.—Table 1 gives the results of maximum-pressure tests upon No. 3 cans with 100 c. c. and with 950 c. c. of water.

TABLE 1.—*Maximum-pressure tests with No. 3 tin cans containing 100 c. c. and 950 c. c. of distilled water.*

Temperatures (° C.).		100 c. c. water.		950 c. c. water.		Temperatures (° C.).		100 c. c. water.		950 c. c. water.	
Sealing.	Processing.	Barometer.	Pressure per square inch.	Barometer.	Pressure per square inch.	Sealing.	Processing.	Barometer.	Pressure per square inch.	Barometer.	Pressure per square inch.
			Lbs.		*Lbs.*				*Lbs.*		*Lbs.*
20	100	29.92	17.06	30.18	14.60	70	100	30.05	10.67	30.18	9.88
	109	29.92	22.70	30.18	20.25		109	30.05	16.26	30.18	15.49
	116	29.92	28.23	30.18	25.40		116	30.05	21.78	30.18	20.74
	121	29.92	32.89	30.18	29.52		121	30.05	26.26	30.18	24.91
50	100	30.08	13.87	30.15	10.99	80	100	29.95	7.97	30.16	7.30
	109	30.08	19.51	30.15	16.36		109	29.95	13.37	30.16	12.70
	116	30.08	25.10	30.15	21.44		116	29.95	18.95	30.16	17.64
	121	30.08	29.60	30.15	25.02		121	29.95	23.50	30.16	21.66
60	100	30.11	12.45	.....	.....	90	100	29.92	4.66	30.05	4.41
	109	30.11	18.04	.....	.....		109	29.92	10.12	30.05	9.51
	116	30.11	23.50	.....	.....		116	29.92	15.46	30.05	14.36
	121	30.11	28.10	.....	.....		121	29.92	20.06	30.05	17.79

Too much importance, of course, should not be attached to one set of figures, as results with individual cans vary somewhat, but the outstanding features shown here have been confirmed by repeated experiments, and the figures presented closely approach the average.

Leading facts disclosed.—From all these tests the following facts seem clear:

(1) With water the pressures developed are always below the theoretical (that with some food materials this does not hold in all cases will be shown later).

(2) The higher the retort temperature, the greater the variation from the theoretical pressures.

(3) The higher the initial temperature, the nearer to the theoretical does the pressure come.

(4) The larger cans show a somewhat greater divergence from the theoretical values than the smaller.

(5) With water, the smaller the head space the less the experimental pressures obtained. The fact that with water the smaller the head space the less the experimental pressures obtained is likewise borne out by experiments with No. 2 cans, using 50 and 550 c. c. of water, the tabulation of the results of which is omitted for lack of space.

Influence of head space.—With cans entirely filled and sealed at any temperature below 100° C. the experimental pressures have been found less than where a head space was allowed. This is explained, of course, by the fact that under these conditions the prime factors operating are vapor pressure and expansion of the water, whereas when a head space is allowed the air pressure also contributes to the

final result. This finding is entirely at variance with the statement of Bitting and Bitting (7, p. 27) that when the container is entirely filled the pressure is greatly increased.

The explanation of the decrease of maximum pressure with decrease of head space is found by a glance at the tables on the distortion of cans and the expansion of water and the theoretical curves of figure 3. By comparison of the expansion of water with the cubical expansion of the can (Tables 1 and 2) it will be seen that the distortion of the can under pressure is always greater than the expansion of water, which results in the creation of a greater head space. Consequently, the ratio between the head space and the distortion of the can is greater the smaller the head space, and therefore with decrease in head space a slight decrease in maximum pressure is to be expected. The greater distortion of the larger can accounts for the greater variation from the theoretical.

Distortion of can and increase in volume.—Every change in pressure causes more or less distortion of the can, which alters its cubical contents. How great this distortion actually is is shown by Table 2, which gives the experimental findings on the increase in volume in No. 2 and No. 3 tin cans when subjected to various internal pressures. These figures present the averages of a number of tests.

TABLE 2.—*Increase in volume of No. 2 and No. 3 tin cans as the result of distortion caused by internal pressures.*

Pressure per square inch in can.	Increase in volume (c. c.).		Pressure per square inch in can.	Increase in volume (c. c.).	
	No. 2 cans.	No. 3 cans.		No. 2 cans.	No. 3 cans.
2½ pounds	5.4	28.3	20 pounds	26.5	65.6
5 pounds	12.1	37.1	25 pounds	31.2	76.9
10 pounds	18.0	46.0	30 pounds	36.7	.....
15 pounds	22.6	54.6			

It will be seen that within the range of canning operations the cubical content of cans may be increased up to 5 per cent or more, depending somewhat upon the size and strength of the individual cans used.

The increase in volume due to distortion of the can explains the decrease in pressure, and since this distortion increases with the higher temperatures greater variations from the theoretical must take place. Inasmuch as sealing at the higher temperatures causes less strain on the can and consequently less distortion when subsequently processed, the theoretical values are more closely approached.

Of less importance also is the influence of the linear expansion of the metal of the can, due to the rise in temperature.

Another fact of much importance in connection with all pressure and vacuum tests is that individual cans vary considerably in their resistance to pressure, whether internal or external. This fact accounts in part for some of the irregularities in the experimental data presented.

Expansion of water.—The expansion of the water due to the rise in temperature likewise has some effect upon the pressure developed. This, while unimportant where the quantity of water is small, may have a considerable influence where the head space is reduced to a minimum; as decreasing the volume of gas in the head space by one-half through expansion of the water after sealing theoretically doubles the pressure developed by the expansion of the inclosed air.

In Table 1 no corrections have been made for this expansion. The tendency, however, is always to increase the variations between the experimental and the theoretical figures.

Table 3, which has been taken from the work of standard authorities (see Smithsonian Physical Tables, Fowle, 7th revised edition, 1920, p. 120; also Kent's Mech. Eng. Pocketbook, 9th edition, 1916, p. 716), shows the increase in volume of a unit quantity of water when passing through the range of temperature with which the present work is concerned.

TABLE 3.—*Volume of water at different temperatures.*

[The mass of 1 cubic centimeter at 4° C. is taken as unity.]

Temperature (° C.).	Volume.	Temperature (° C.).	Volume.	Temperature (° C.).	Volume.
0	1.00013	40	1.00782	85	1.03237
4	1.00000	45	1.00985	90	1.03590
5	1.00001	50	1.01207	95	1.03955
10	1.00027	55	1.01448	100	1.04343
15	1.00087	60	1.01705	110	1.0515
20	1.00177	65	1.01979	115.5	1.0560
25	1.00293	70	1.02270	121.1	1.0661
30	1.00434	75	1.02576		
35	1.00598	80	1.02899		

Table 4, which is based upon the foregoing, shows the actual increase in volume of water in No. 2 and No. 3 tin cans when sealed at various temperatures and processed at 100°, 110° 115.5°, and 121.1° C., the initial volume of the water in the No. 2 can being taken as 550 c. c. and in the No. 3 as 950 c. c. The figures are self-explanatory.

TABLE 4.—*Increase in the volume of water in No. 2 and No. 3 tin cans when processed at different temperatures, the initial volume in No. 2 cans being 550 c. c. and in No. 3 cans, 950 c. c.*

[Based on Smithsonian tables.]

Temperatures (° C.).		Volume (c. c.).			
		No. 2 cans.		No. 3 cans.	
Sealing.	Processing.	Total.	Increase.	Total.	Increase.
20	100	572.8	22.8	989.4	39.4
	110	577.2	27.2	997.0	47.0
	115.5	579.7	29.7	1,001.3	51.3
	121.1	585.3	35.3	1,010.9	60.9
70	100	561.1	11.1	969.2	19.2
	110	565.4	15.4	976.7	26.7
	115.5	567.9	17.4	984.9	34.9
	121.1	673.3	23.3	990.3	40.3
80	100	557.7	7.7	963.3	13.3
	110	562.0	12.0	970.8	20.8
	115.5	564.4	14.4	974.9	24.9
	121.1	569.8	19.8	984.2	34.2

Relation of barometric pressure.—A factor of considerable importance concerned with vacuum in cans is the barometric pressure, especially as related to differences in altitude. Table 5 shows the differences in barometric pressure for altitudes ranging from sea level to approximately 6,000 feet and how, for example, food materials packed at or near sea level would lose in vacuum by over 3 inches, under identical temperature conditions, when shipped to a place 3,000 feet above sea level. This loss would be increased, of course, if those shipments were made to hot climates or during the summer.

TABLE 5.—*Barometric pressure for different altitudes.*

[Taken from Smithsonian Meteorological Tables, 4th rev. ed., 1918, pp. 136–137.]

Altitude.	Barometric pressure.	Altitude.	Barometric pressure.	Altitude.	Barometric pressure.	Altitude.	Barometric pressure.
0 (sea level)	29.90	607 feet	29.24	1,504 feet	28.29	3,998 feet	25.81
100 feet	29.79	700 feet	29.14	1,999 feet	27.78	4,498 feet	25.34
210 feet	29.68	803 feet	29.03	2,502 feet	27.27	5,006 feet	24.80
302 feet	29.57	906 feet	28.92	3,005 feet	26.77	5,503 feet	24.42
403 feet	29.46	1,000 feet	28.82	3,497 feet	26.29	5,997 feet	23.98
505 feet	29.35						

While these matters may not be of great importance it is probable that the unfortunate experience of some canners has been due to some of these factors or to a combination of them.

VACUUM STUDIES.

Vacuum readings obtained in tests.—To determine how closely experimental results with tin cans would agree with the theoretical

figures, to assist in the selection of the best sealing temperatures, and to obtain a base line for comparing various food materials, vacuum tests were made with No. 2 and No. 3 cans containing 550 and 950 c. c. of water, respectively, sealed at different temperatures and cooled to room temperature. The experimental data are shown for the No. 3 cans in Table 6. Figures for the No. 2 cans are omitted, as they do not vary essentially from those of the No. 3 cans except in having a slightly greater vacuum, due to greater resistance to external pressure.

TABLE 6.—*Vacuum readings obtained with No. 3 tin cans containing 950 c. c. of water sealed at different temperatures and cooled.*

Temperatures (° C.).		Barometer readings.		Vacuum reading (inches of mercury).
At sealing.	After cooling.	At sealing.	After cooling.	
50	16¼	30.19	30.43	8.62
60	18	30.39	30.18	10.12
70	19	30.18	30.16	11.75
80	20	30.16	30.05	13.87
90	19¼	30.05	30.18	19.00

Leading facts developed in comparisons of these findings with the theoretical curves show the following:

(1) At the sealing temperatures of 70° C. and above the vacuums obtained are below the theoretical. This is to be expected, of course, inasmuch as the same factors which affect recorded pressures, discussed above, are operative here, although working in the other direction. That is, contraction takes place instead of expansion; the temperatures are lowered instead of increased; the can is distorted inward by external pressure instead of outward, etc.

(2) The higher the sealing temperature the greater the variation from the theoretical vacuums.

(3) In these tests the cans sealed at the lower temperatures show vacuums slightly above their theoretical values. This was found, after examining the cans, to be due to permanent distortion of the cans during processing, for the vacuum readings were made on the cans employed in the above pressure tests which after cooling did not return to their normal shape. If the cans are sealed at these temperatures and cooled immediately to the desired temperature, the vacuum is slightly below the theoretical.

RATE OF TEMPERATURE CHANGE WITHIN THE CAN.

From the above statement it is obvious that in order to avoid undue strain upon cans, and for other reasons mentioned, the temperature of sealing should be considerably above room temperature. The question then immediately arises, How will this affect the length of time required to secure the proper temperature in the can? To shed light upon this matter and to obtain a base line for the comparison of the various food substances, tests were made upon the rate of temperature changes in distilled water. Figure 6 shows the results of these

tests, using No. 3 cans sealed at different temperatures and processed at 116° C.

The temperature of the retort is reached only one to one and one-half minutes sooner when the initial temperature is 80° than when it is 20° C. A comparison of these curves with similar ones for different food substances shown later will be found to be of interest. Cooling curves are also shown for the No. 3 can cooled from 116° in water at constant temperature to 60° and 20° C., respectively. While, as in the heating, the temperature changes within the can take place very rapidly, the heating and the cooling curves are not the exact reverse

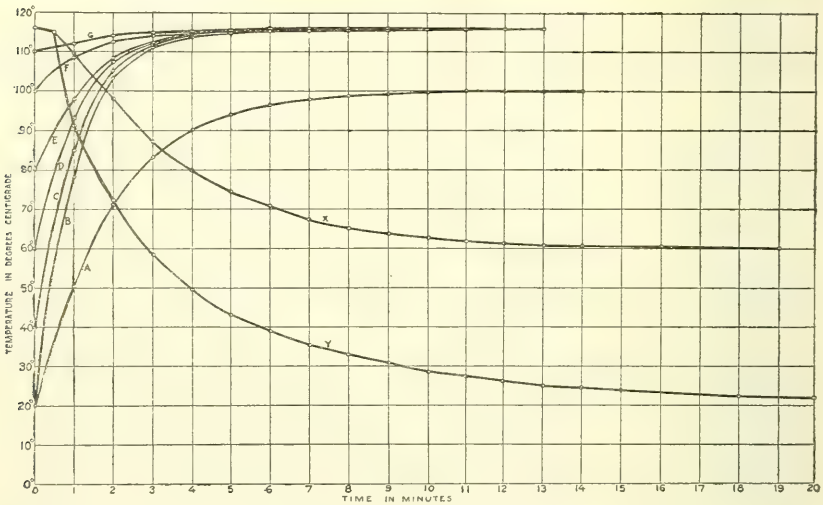

FIG. 6.—Experimental time-temperature curves for distilled water in No. 3 tin cans, starting at different uniform temperatures and processed at 116° C. The heating curve is shown for a can starting at 20° C. and processed at 100° C.; and curves showing the rate of cooling in water at different temperatures. Curve for can starting: *A*, At 20° C. and processed at 100° C.; *B*, at 20° C. and processed at 116° C.; *C*, at 40° C. and processed at 116° C.; *D*, at 60° C. and processed at 116° C.; *E*, at 80° C. and processed at 116° C.; *F*, at 100° C. and processed at 116° C.; *G*, at 110° C. and processed at 116° C.; *X*, at 116° C. and cooled in water at 60° C.; *Y*, at 116° C. and cooled in water at 20° C.

of each other. This is due in part, of course, to the fact that the viscosity of water changes with changes in temperature. As the temperature in the can approaches the temperature of the cooling bath there is a flattening out of the curve, due in part to the increase in viscosity of the water, which is much more marked than in the corresponding portion of the heating curve, where the viscosity is continuously diminishing and the time required to effect the complete change is materially lengthened.

Figure 7 shows the rate of temperature change at the center of a quart glass jar with water sealed at different temperatures and processed at 100° C.

The effect of initial temperature is easily seen from the curves. The temperature of the retort is reached six or seven minutes sooner when the initial temperature is 80° C. than when it is 20° C. It is apparent, therefore, that the initial temperature is of more significance when canning in glass than when canning in tin in those substances where there is free liquid filling the interspaces of the product.

Another matter of much importance is the study of the changes in temperature necessary to secure the proper exhaust. When a No. 2 can of water having an initial temperature of 20° C. is exhausted for 1 minute at 100° C. the temperature reaches to about 60° C. A No. 3 can reaches about 50° C. The rate of change of temperature

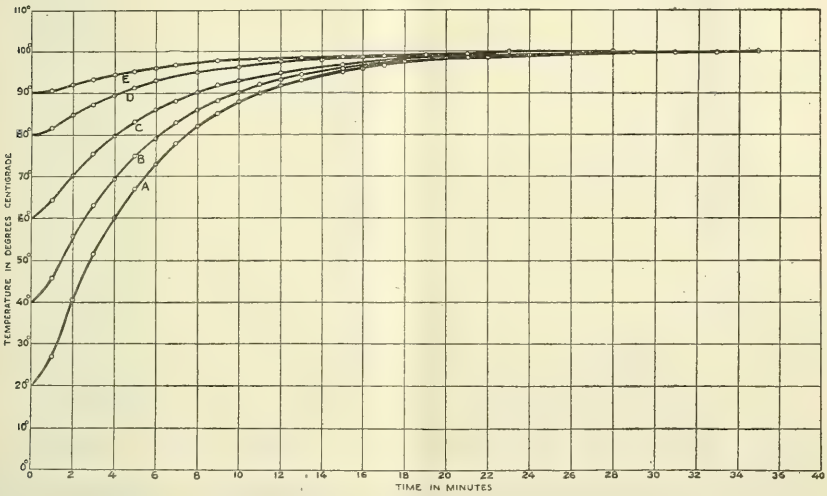

FIG. 7.—Experimental time-temperature curves for quart glass jars of distilled water, starting at different temperatures and processed at 100° C. Curve for jar starting: *A*, At 20° C.; *B*, at 40° C.; *C*, at 60° C.; *D*, at 80° C.; *E*, at 90° C.

when exhausted at 100° is shown in figure 6, curve A. The application of these facts to the exhausting of various food substances will be considered and illustrated later.

EXPERIMENTS WITH SPECIFIC FOOD MATERIALS.

STRING BEANS.

PRESSURE STUDIES.

The tests upon string beans were carried out as follows: The beans were gathered fresh from the field, washed, broken into pieces 1 to 1½ inches in length, and then blanched in boiling water for four minutes. For each one of the tests with the No. 2 can 350 grams of beans were used and 220 c. c. of liquor, which gave approximately normal head space. In the case of the No. 3 can, 600 grams of beans and 360 c. c. of liquor were used.

Figure 8 shows the pressure curves for the No. 2 can when sealed at the temperatures of 22° to 24½°, 70°, and 80° C. and processed at 100°, 116°, and 121° C. Figure 9 shows the same for the No. 3 can.

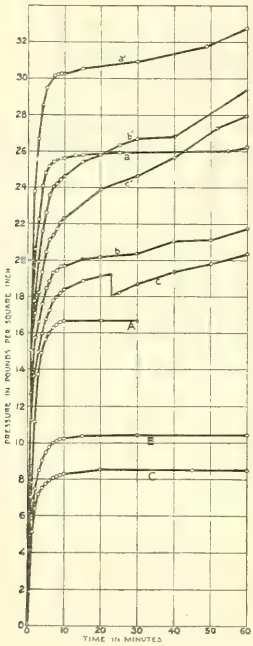

FIG. 8.—Experimental time-pressure curves for No. 2 cans of string beans sealed at different uniform temperatures and processed for 1 hour at 100°, 116°, and 121° C., 350 grams of beans, 220 c. c. of liquor. Curve for can sealed: *A*, At 24½° C. and processed at 100° C.; *a*, at 24½° C. and processed at 116° C.; *a'*, at 22° C. and processed at 121° C.; *B*, at 70° C. and processed at 100° C.; *b*, at 70° C. and processed at 116° C.; *b'*, at 70° C. and processed at 121° C.; *C*, at 80° C. and processed at 100° C.; *c*, at 80° C. and processed at 116° C.; *c'*, at 80° C. and processed at 121° C.

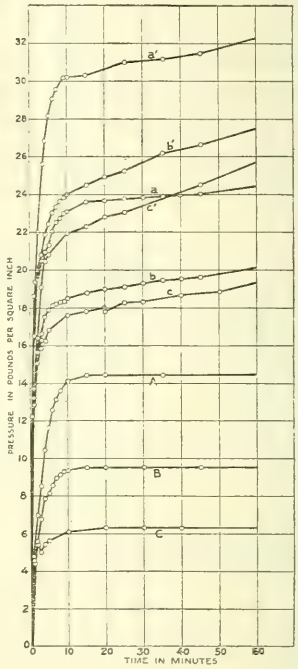

FIG. 9.—Experimental time-pressure curves for No. 3 tin cans of string beans sealed at different uniform temperatures and processed at 100°, 116°, and 121° C., 600 grams of beans, 360 c. c. of liquor. Curve for can sealed: *A*, At 20¾° C. and processed at 100° C.; *a*, at 30° C. and processed at 116° C.; *a'*, at 22° C. and processed at 121° C.; *B*, at 70° C. and processed at 100° C.; *b*, at 70° C. and processed at 116° C.; *b'*, at 70° C. and processed at 121° C.; *C*, at 80° C. and processed at 100° C.; *c*, at 80° C. and processed at 116° C.; *c'*, at 80° C. and processed at 121° C.

The form of the curves during the first few minutes of the process is entirely similar to those for distilled water, and in the case of those cans processed at 100° C. the entire curves agree closely. The maximum pressures are approached in 15 minutes. Striking differences

from the distilled-water curves are noted, however, in the case of those curves for cans processed at 116° and 121° C., in which an equilibrium is not attained throughout the entire period of the tests. Furthermore, these differences are increased with the higher processing temperatures, the final portion of the curves for cans processed at 121° C. being steeper than those for cans processed at 116° C. That this has no correlation with the rate of heat penetration is shown by the fact that the increase in pressure is continued long after the equilibrium of temperature has been reached. Experiments show that a temperature equilibrium is reached in string beans in about 15 minutes in the No. 2 and in 18 to 22 minutes in the No. 3 can. In one case during the present tests the pressure continued to increase for four hours after the processing was begun, at which time the experiment was terminated.

This seems to indicate that at the higher temperature there is a decomposition of the material in the can, with a consequent liberation of gases. It was thought that the setting free of hydrogen by the action of the food material on the metal of the container, as pointed out by Bigelow (1) might explain this result, but comparative tests, using both plain and enameled cans under these conditions, failed to give evidence in support of this view.

These curves also illustrate how strains are greatly lessened by sealing at as high temperatures as practicable, especially when processing is to be done at the higher retort temperatures. It will be seen that even when cans are sealed at temperatures as high as 80° C. the pressures obtained are well above the theoretical values.

The processing period in these tests, except in the single instance noted, was 1 hour. This may not conform to regular practice, but the maximum pressures for any period less than this will be shown on these curves, for when the steam in the retort is cut off the pressure in the can begins to fall almost immediately.

The actual strain on the can at any time during the process may be found by subtracting the retort pressure from the pressure indicated for that time in the curve. When the retort pressure is released, however, the strain on the can is greatly increased. If a complete release of pressure in the retort should be effected instantaneously the full pressure indicated would be felt, but the gradual decline in retort pressure in practice favors the can somewhat. The greatest strain occurs when the pressure in the retort reaches zero, but at this point the strain is, however, only 3 to 5 pounds, or (in some cases more than this) less than the maximum pressure indicated in the curve. The extent of this variation from indicated pressures is dependent upon the temperature of sealing, the processing temperature, the nature of the material, the amount of bulging of the can, and the rate of release of pressure in the retort. When processing is done at

100° C. there is no retort pressure to counterbalance that of the can, and consequently the pressures indicated represent actual strains on the cans.

Sharp breaks and occasional irregularities in the form of the curves are due to sudden bulging and gradual distortion of the cans. Small variations due to differences in the resistance of individual cans are to be noted.

VACUUM STUDIES.

Vacuum tests were made upon the cans used in the pressure tests recorded here by cooling the cans to about room temperature and then reading the vacuum with the mercury manometer, as previously described. Table 7 shows the results obtained for the No. 2 cans. Figures for the No. 3 cans are omitted, as, aside from showing a slightly smaller vacuum, due primarily to the lesser resistance of the larger can to external pressure, they are similar.

TABLE 7.—*Vacuum tests with string beans.*

Temperatures (° C.).			Barometer reading.		Vacuum (inches of mercury).
Sealing.	Processing.	After cooling.	At sealing.	After cooling.	
70	100	20½	29.89	29.86	12½
	116	19⅜	29.86	29.86	11¾
	121	18⅞	29.86	30.05	11¾
80	100	22½	29.86	29.82	15⅜
	116	18½	30.05	30.05	13¾
	121	19	30.05	30.05	13 1/16

These figures show that experimental vacuums in string beans are always below the theoretical and that the higher the processing temperature employed the lower the vacuum obtained. This may amount to 2 inches or more. This may be due in part to the pressure of air included in the material which is not expelled during the preliminary blanching and in part to individual differences in cans, but it is probably due primarily to the liberation of gases during the processing.

Cans of string beans in lots sealed at 20°, 50°, 60°, 70°, 80°, 90°, and 100° C. were prepared for vacuum readings and for concussion tests, but the percentage of leaky cans was so great that the results were not considered of sufficient value to present here.

HEAT PENETRATION.

From the foregoing discussion of pressures developed in the can it is obvious that sealing temperatures well above room temperatures should be employed when canning in tin. It is important, therefore, to have a full knowledge as to the temperature changes occurring when the initial temperatures are different. Figure 10 shows the effect of

different initial temperatures on the rate of temperature change in a No. 2 can of string beans packed rather closely and processed at

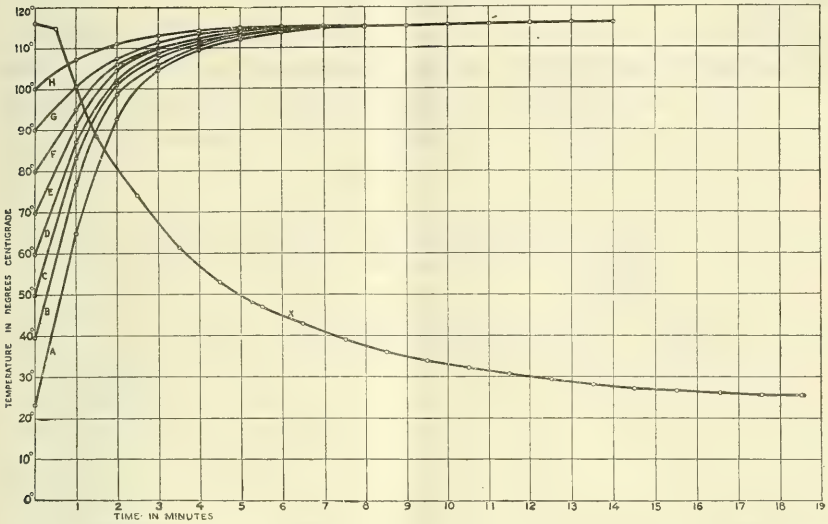

FIG. 10.—Experimental time-temperature curves for No. 2 cans of string beans, starting at different uniform temperatures and processed at 116° C. Curve is also shown for cooling in water at 25° C. Curve for can starting; *A*, At 23° C.; *B*, at 40° C.; *C*, at 50° C.; *D*, at 60° C.; *E*, at 70° C.; *F*, at 80° C.; *G*, at 90° C.; *H*, at 100° C.; *X*, at 116° C. and cooled in water at 25° C.

116° C. The cooling curve for a No. 2 can cooled in water having a constant uniform temperature of 25° C. is also given.

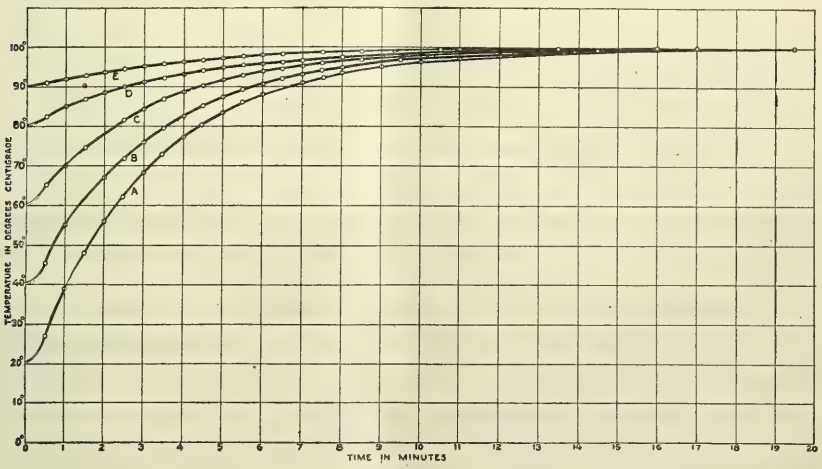

FIG. 11.—Experimental time-temperature curves for string beans in quart glass jars, starting at different uniform temperatures and processed at 100° C. Curve for jar starting: *A*, At 20° C.; *B*, at 40° C.; *C*, at 60° C.; *D*, at 80° C.; *E*, at 90° C.

In figure 11 are shown the experimental heat-penetration curves for beans in a quart glass jar processed at 100° C.

Figure 12 shows curves for a No. 2 can of beans not packed so closely as in the test cans of figure 10, but processed at 100°, 116°, and 121° C.

Figure 13 is the same for a No. 3 can, and in addition the curve for cooling in water at the constant temperature of 20° C. is shown.

A study of the foregoing curves shows that the retort temperature is reached only slightly sooner in the No. 2 can sealed at 80° than in the can sealed at 20° C. and that the effect of differences in initial

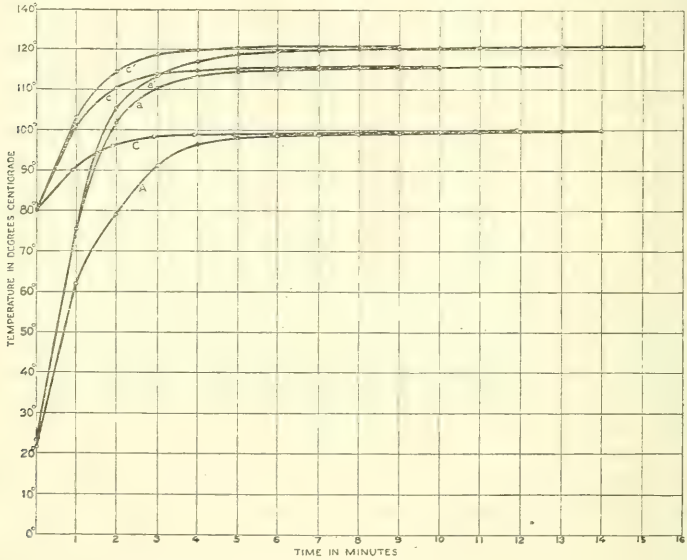

FIG. 12.—Experimental time-temperature curves for No. 2 cans of string beans, starting at different uniform temperatures and processed at different temperatures. Curve for can starting: *A*, At 21° C. and processed at 100° C.; *a*, at 23° C. and processed at 116° C.; *a'*, at 23° C. and processed at 121° C.; *C*, at 80° C. and processed at 100° C.; *c*, at 80° C. and processed at 116° C.; *c'*, at 80° C. and processed at 121° C.

temperature is more marked when canning in glass than when canning in tin, since the jar starting at 80° requires six or seven minutes less to reach retort temperature than that started at 20° C.

The differences in the heating curves of cans sealed at the various initial temperatures are of relatively small practical importance in substances like string beans and need be considered only when the minimum processing periods are employed. This accounts for the rather uniform results obtained in some canning practices where the initial temperatures vary considerably. It should be remembered, however, that the total amount of exposure to heat is somewhat greater with the higher initial temperature.

As previously noted, the time-temperature curves both for the heating and the cooling are similar to those for distilled water, and

here again is emphasized the fact that the cooling curves are not the exact reverse of the heating curves, for the final portion of the cooling curve is flatter than the corresponding portion of the heating curve. No curves for cooling in air are shown here, but tests show that it is very much slower than cooling in water.

PEAS.

PRESSURE STUDIES.

Peas used for the pressure tests were shelled, blanched in boiling water for four minutes, drained, and then weighed into the test cans.

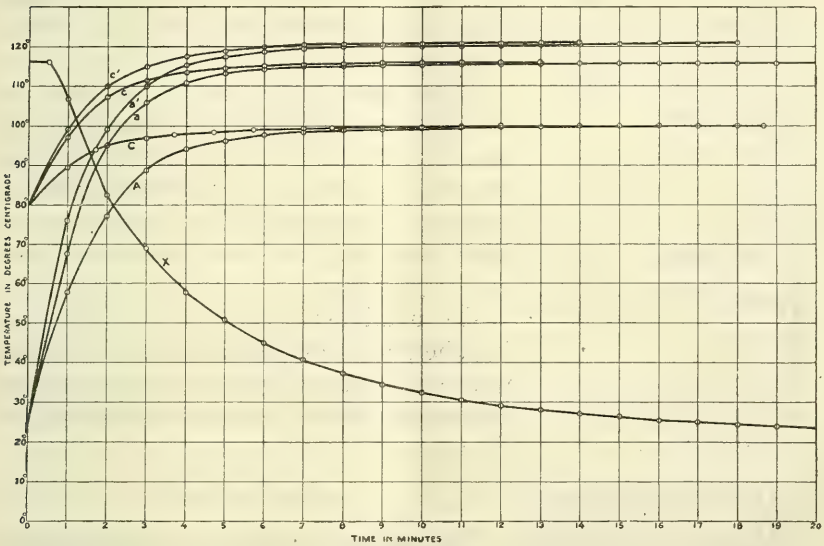

FIG. 13.—Experimental time-temperature curves for string beans in No. 3 tin cans starting at different uniform temperatures and processed at 100°, 116°, and 121° C. Curve is also shown for cooling in water at 20° C. Curve for can starting: *A*, At 26° C. and processed at 100° C.; *a*, at 26° C. and processed at 116° C.; *a'*, at 25° C. and processed at 121° C.; *C*, at 80° C. and processed at 100° C.; *c*, at 80° C. and processed at 116° C.; *c'*, at 80° C. and processed at 121° C. *X*, Cooling curve for can starting at 116° C. and cooled in water at 20° C.

For the No. 2 can 400 grams of peas and 170 c. c. of liquor were used. The cans were sealed at the initial uniform temperatures of 20°, 70°, and 80° C., respectively, and processed for one hour at 100°, 116°, and 121° C. Figure 14 shows the time-pressure curves for these cans, together with one curve for unblanched peas sealed at 19° and processed at 116° C.

As in the case of string beans, cans processed at 100° C. approached an equilibrium of pressure in a length of time corresponding closely to that required to reach a temperature equilibrium, that is about 15 minutes. At the higher processing temperatures the continued rise in pressure is again noted, though in the case of the cans sealed at

20° and processed at 116° and 121° C., respectively, the pronounced and repeated bulging of the cans masks this effect. The decomposition of the material under test, if such is the explanation, is less marked than in the string beans, but is nevertheless exhibited.

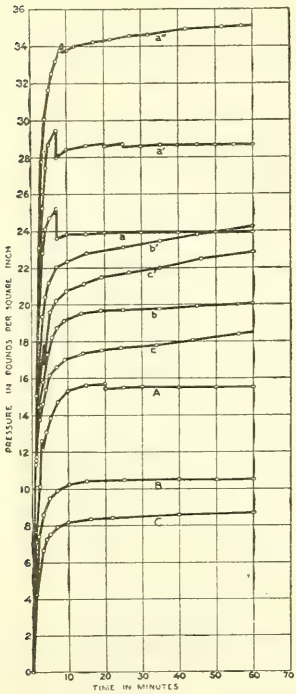

FIG. 14.—Experimental time-pressure curves for peas in No. 2 tin cans sealed at different uniform temperatures and processed at 100°, 116°, and 121° C.; 400 grams of peas, 170 c. c. of liquor. Curve for can sealed: *A*, At 20° C. and processed at 100° C.; *a*, at 20° C. and processed at 116° C.; *a'*, at 20° C. and processed at 121° C.; *a''*, at 19° C. and processed at 116° C., peas unblanched; *B*, at 70° C. and processed at 100° C.; *b*, at 70° C. and processed at 116° C.; *b'*, at 70° C. and processed at 121° C.; *C*, at 80° C. and processed at 100° C.; *c*, at 80° C. and processed at 116° C.; *c'*, at 80° C. and processed at 121° C.

The relation of blanching to the development of pressures is clearly shown by the comparison of the curves for the blanched and the unblanched peas sealed at low temperatures and processed at 116° C. Approximately 11 pounds greater pressure was developed in the can of unblanched material.

In the work with peas it has been observed that the stage of maturity, the amount of blanching, and the fullness of the can have more or less effect upon the pressure developed. The influence of these factors is not here illustrated with curves, however.

The maximum pressures attained during the period of processing used in these tests (60 minutes) were slightly below the theoretical values, but above those for distilled water.

VACUUM STUDIES.

The vacuum readings made on the cans used in the pressure tests gave results entirely comparable with those for string beans. The vacuums obtained were somewhat below the theoretical values and slightly above those for beans. The effect at the higher temperatures was again observed, the reading in the case of the cans processed at 116° and 121° C. being lower by approximately 2 inches than those processed at 100° C.

Those factors which affect the development of pressure in peas likewise influence the vacuum. The amount of blanching, the maturity of the peas, the liberation of gases during processing, the bulging of cans, and the individual variations in the resistance of cans to external pressure all affect the vacuum readings.

In concussion tests upon cans in lots sealed at the various temperatures the results were somewhat variable, but differences in the resistance of No. 2 cans to denting did not seem to be very marked with sealing temperatures up to 70° or 80° C. Above 80° the susceptibility to denting became more and more marked and between 95° and 100° C. the cans usually collapsed spontaneously. The No. 3 cans were more susceptible to denting than the No. 2 size and their susceptibility became more and more marked above 75° C. With sealing temperatures between 90° and 95° C. the can usually collapsed spontaneously or with very slight pressure.

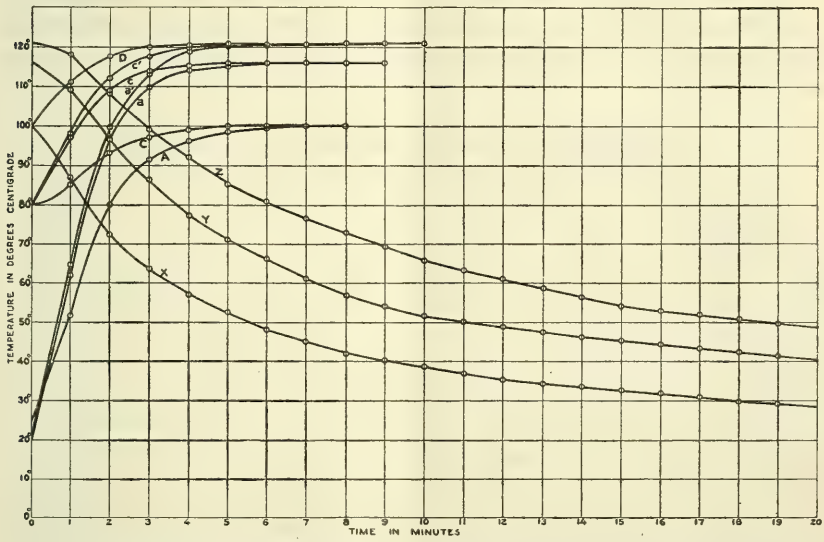

FIG. 15.—Experimental time-temperature curves for peas in No. 2 tin cans, starting at different uniform temperatures and processed at 100°, 116°, and 121° C. Curves are also given for cooling from different temperatures in water at 24° C. Curve for can starting: *A*, At 26° C. and processed at 100° C.; *a*, at 20° C. and processed at 116° C.; *a'*, at 21° C. and processed at 121° C.; *C*, at 80° C. and processed at 100° C.; *c*, at 80° C. and processed at 116° C.; *c'*, at 80° C. and processed at 121° C.; *D*, at 100° C. and processed at 121° C. Cooling curve for can starting: *X*, At 100° C. and cooled in water at 24° C.; *Y*, at 116° C. and cooled in water at 24° C.; *Z*, at 121° C. and cooled in water at 24° C.

HEAT PENETRATION.

The results of experiments on the rate of change of temperature in No. 2 cans of peas having different temperatures are shown in figure 15. These show that when cans are sealed at the various initial temperatures and processed at the same retort temperatures the heat penetration curves closely approach each other in the first four or five minutes of the process, and the difference in the length of time required to reach retort temperature amounts to only two or three minutes. The curves do not differ markedly from those for distilled water. The rate of temperature change in glass, although not shown here, is considerably slower than in the tin and agrees closely with that shown for string beans.

From the curves it is obvious that only a short exhaust is necessary for peas, two to four minutes being ample if sealing follows immediately. Emphasis must be laid on prompt sealing, however, as the air of the head space cools more rapidly than the material, and unless sealing is effected at once abnormal or too high pressures are developed during the processing and too low vacuums are obtained on cooling.

The cooling curves are of interest in that they show again how, in material like peas, the starch and other substances which are cooked out alter the viscosity of the liquor, causing the form of the cooling curves when temperatures are reversed to vary considerably from that of the heating curves. This is more marked in peas than in string beans. The curves also show how the viscosity is increased

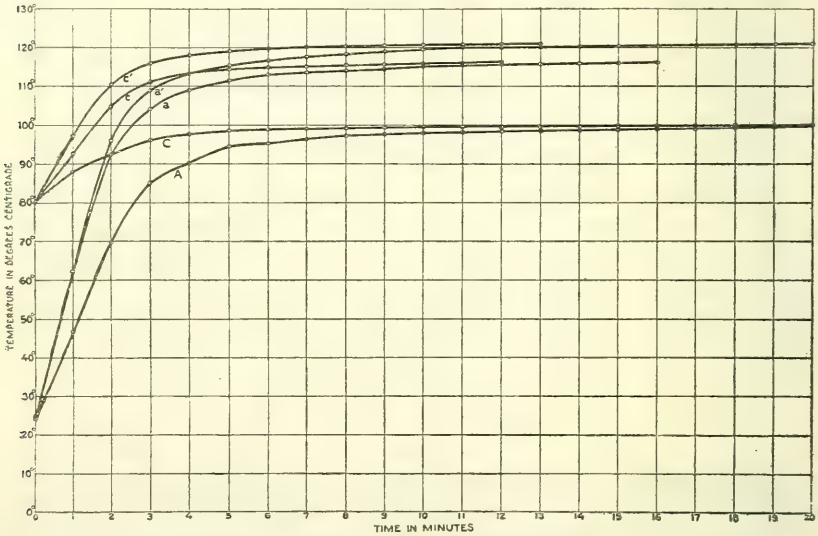

FIG. 16.—Experimental time-temperature curves for peas in No. 3 tin cans, starting at different uniform temperatures and processed at 100°, 116°, and 121° C. Curve for can starting: *A*, At 24° C. and processed at 100° C.; *a*, at 24½° C. and processed at 116° C.; *a'*, at 24½° C. and processed at 121° C.; *C*, at 80° C. and processed at 100° C.; *c*, at 80° C. and processed at 116° C.; *c'*, at 80° C. and processed at 121° C.

by the higher processing temperatures. The viscosity will also be affected by the degree of maturity of the peas and the length of the processing period.

Figure 16 shows curves for the No. 3 can and illustrates how, because of the rapidity with which temperature changes occur, processing periods for No. 2 and No. 3 cans need differ but little; that is, four or five minutes.

There are several factors which will make the temperature change during processing vary slightly. If in any way a number of peas get broken the starch will come out of these more readily and will make the rate of change of temperature slightly slower. The more mature the peas the greater will be this effect. The proportion of peas to liquor will have a small effect also. If the proper quantity

of liquor has not been added the rate of change of temperature will be slightly slower. These differences are usually insignificant in common practice, in so far as such variations affect the length of the processing period.

TOMATOES.

PRESSURE STUDIES.

The tests upon tomatoes varied from those upon other substances in that the time-pressure curves were determined after different ex-

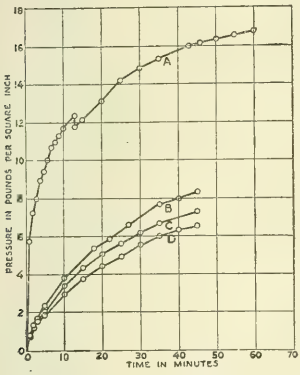

FIG. 17.—Experimental time-pressure curves for tomatoes in No. 2 tin cans, showing the effect of different periods of exhaust upon pressures developed during a processing period of 45 minutes at 100° C. Curve for can: *A*, Receiving no exhaust; *B*, exhausted for 2 minutes at 100° C., before processing; *C*, exhausted for 4 minutes at 100° C., before processing; *D*, exhausted for 6 minutes at 100° C., before processing.

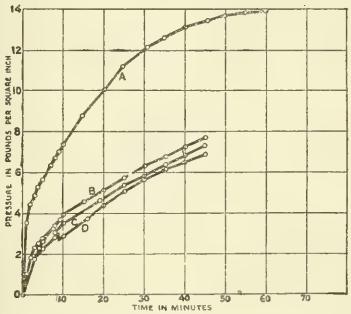

FIG. 18.—Experimental time-pressure curves for tomatoes in No. 3 tin cans, showing the effect of different periods of exhaust upon pressures developed during the processing period of 45 minutes at 100° C. Curve for can: *A*, Receiving no exhaust; *B*, exhausted for 2 minutes at 100° C., before processing; *C*, exhausted for 4 minutes at 100° C., before processing; *D*, exhausted for 6 minutes at 100° C., before processing.

haust periods. The tomatoes were peeled without scalding and weighed directly into the test cans, 550 grams being used in the No. 2 and 950 in the No. 3 cans. The initial temperature in all cases was between 22° and 25° C. The brass attachment was soldered to the can, which was then placed in the retort in the usual manner. In the case of the can receiving no exhaust, sealing was effected immediately and the test begun. The processing in all cases was at 100° C. In succeeding tests after placing the cans in the retort the steam was turned on and as soon as the retort temperature reached 100° C. (which was close to 30 to 45 seconds), time was taken and the cans exhausted for 2, 4, and 6 minutes, respectively. At the end of the exhaust period the can was immediately sealed, as previously described, and the time-pressure figures obtained.

Figure 17 shows the curves obtained for the No. 2 and figure 18 those for the No. 3 cans.

The outstanding feature of these curves is the fact that by far the greatest reduction in pressure during the 45-minute process period occurred as the result of the first two minutes of the exhaust. In the case of the No. 2 can this was a reduction of about 7 to 8 pounds per square inch during the first two minutes, which was lowered only about 1.8 pounds further by a 6-minute exhaust. The curves for the No. 3 can show the same thing, except that the maximum pressure developed in the can not exhausted was not so great. It is obvious that the temperature of the head space is the greatest factor in determining the vacuum and pressure, for the average of the can at the end of two minutes could not be high enough to account for the low pressure and high vacuum thus obtained. The effectiveness of a short exhaust, as in the case of peas, would be realized only by immediately sealing, as will be shown later by the results of vacuum tests on cans in lots which were exhausted in the steam box for the different exhaust periods and then removed and sealed at once.

VACUUM STUDIES.

The figures for the vacuum obtained in the cans used in the pressure tests which are of interest are presented in Table 8:

TABLE 8.—*Vacuum tests with tomatoes in No. 2 and No. 3 tin cans.*

Size of cans.	Temperature (°C.).		Time (minutes).		Barometer reading.		Vacuum (inches of mercury).
	Material at the start.	After cooling.	Exhaust.	Length of process.	At sealing.	After cooling.	
No. 2	24	16½	2	45	29.85	29.80	15
	23¼	17	4	45	29.80	29.73	16⅞
	23	19	6	45	29.39	29.39	17½
No. 3	25¼	22¾	2	45	29.86	29.85	15
	25	22	4	45	29.80	29.80	15
	24	21½	6	45	29.73	29.39	16

With the increase in exhaust there is slight increase in vacuum, which corresponds well with the figures on pressures, and they are found to be fairly high.

The average vacuum readings upon No. 3 cans in lots, exhausted for different periods in the steam box and then sealed in the mechanical sealing machine, were as follows:

1-minute exhaust ..... 3 inches.
2-minute exhaust ..... 3½ inches.
3-minute exhaust ..... 4 inches.
4-minute exhaust ..... 6½ inches.
5-minute exhaust ..... 8 inches.

It is seen that these values are considerably below those in which the cans were sealed while still in the retort, and they illustrate how

the temperature of the head space at the time of sealing affects the vacuum. In this case the head space cooled considerably during the few seconds required to transfer the cans from the exhaust box to the sealing machine.

HEAT PENETRATION.

Figure 19 shows the experimental time-temperature curves for tomatoes in No. 2 cans starting at the initial temperature of 30° C. and processed at 100° for 20, 25, 30, and 35 minutes and then cooled in the air at room temperature, or about 20° C.

Though the cans were removed from the retort to the air, the temperature continued to rise for 25 to 30 minutes in the can processed for 20 minutes, and in the can processed for 35 minutes the rise continued for 20 to 25 minutes. If we assume sterilization processes to begin at 80° C., it will be seen that in the cans processed for 20 and 25 minutes the tomatoes at the center of the cans did not reach the sterilizing point at any time during the process. When processed 30 minutes the temperature remained above 80° C. for 25 to 30 minutes and when processed 35 minutes for about 45 minutes.

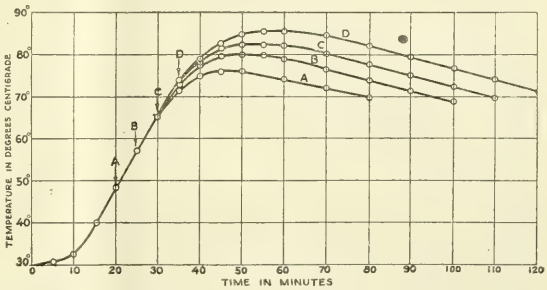

FIG. 19.—Experimental time-temperature curves for tomatoes in No. 2 tin cans, starting at a uniform temperature of 30° C., processed for 20, 25, 30, and 35 minutes at 100° C., and then cooled in air at ordinary room temperature. The arrows indicate when cans were taken from the retort. Curve for can processed: *A*, For 20 minutes; *B*, for 25 minutes; *C*, for 30 minutes; *D*, for 35 minutes.

These curves represent the averages for a number of tests. Owing to differences in maturity, difficulty in preparing uniform packs, and other factors, the time-temperature curves for tomatoes are found to be quite variable. It is believed, however, that the average conditions are fairly accurately illustrated by the above curves.

These curves show how very limited in usefulness is a time-temperature curve established under conditions that carry it entirely to the temperature of the retort. It gives very little idea of what temperature will be reached when processed for a definite time shorter than the time necessary to carry the center of the can to the temperature of the retort.

CORN.

PRESSURE STUDIES.

The corn used in these tests was gathered in prime table condition fresh from the field, husked and silked in the usual manner and cut from the cob "Maine style." It was then weighed and liquor added

to give the proportion of corn to liquor of 4 to 1. The corn was then precooked over steam with constant stirring until the temperature reached 80° C. It was then weighed into the No. 2 test cans, 550 grams being used in each case, brought to the desired uniform temperatures, sealed, the tests immediately begun, and the time-pressure curves determined. This procedure held for those cans sealed at 70° and 80° C. The procedure was the same with the cans sealed at 20° to 24½° C., except that in one set of experiments the corn was precooked to 100° and in the other the corn was placed in the test cans without any precooking at all. Processing in all cases was for 120 minutes or thereabouts at the retort temperatures of 100°, 116°, and 121° C., respectively. Figure 20 shows the curves obtained in these tests.

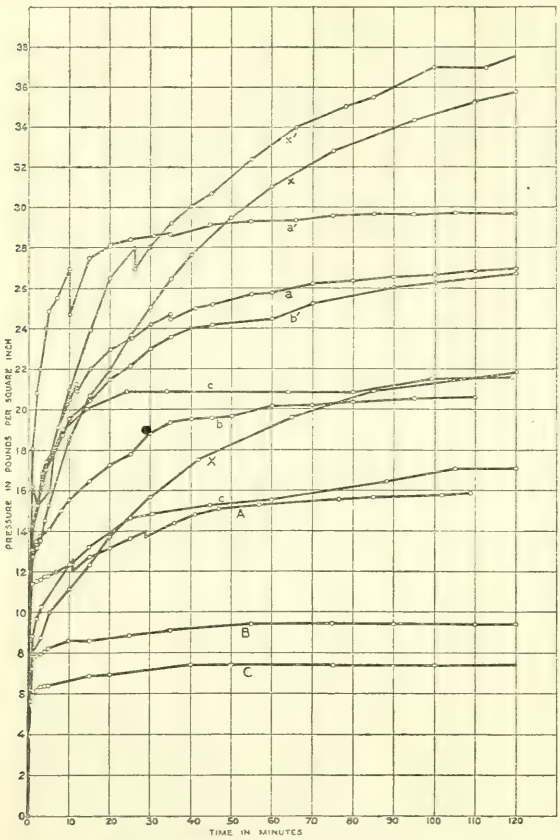

FIG. 20.—Experimental time-pressure curves for corn in No. 2 tin cans, sealed at different uniform temperatures and processed for 2 hours at 100°, 116°, and 121° C. Prepared "Maine style"; 550 grams of material used. Proportion of corn to liquor, 4:1. Curve for corn: *A*, Precooked at 100° C., sealed at 24½° C., and processed at 100° C.; *a*, precooked to 100° C., sealed at 24½° C., and processed at 116° C.; *a'*, precooked to 100° C., sealed at 24½° C., and processed at 121° C.; *B*, precooked to 80° C., sealed at 70° C., and processed at 100° C.; *b*, precooked to 80° C., sealed at 70° C., and processed at 116° C.; *b'*, precooked to 80° C., sealed at 70° C., and processed at 121° C.; *C*, precooked to 80° C., sealed at 80° C., and processed at 100° C.; *c*, precooked to 80° C., sealed at 80° C., and processed at 116° C.; *c'*, precooked to 80° C., sealed at 80° C., and processed at 121° C.; *X*, with no precooking, sealed at 20° C., and processed at 100° C.; *x*, with no precooking, sealed at 24½° C., and processed at 116° C.; *x'*, with no precooking, sealed at 24½° C., and processed at 121° C.

These curves demonstrate the following facts:

(1) The pressure rises almost immediately to a high point when the steam is turned on, as a result of the sudden expansion of the air of the head space. After the first minute the rise is more gradual, the rate corresponding largely to the rate of temperature change in the corn.

(2) Relatively low pressures are obtained when the higher sealing temperatures are employed.

(3) Great pressures are developed when the corn is not precooked, owing to the swelling of the starch and to the included air.

(4) The continued rise in pressure due to the liberation of gases, while shown, is partially masked, for the reason that the temperature at the center of the can did not reach the retort temperature during the processing period.

(5) The rate of rise in pressure during processing is greater at the higher processing temperatures.

(6) The maximum pressures are all somewhat below the theoretical and somewhat (except in the case of those not precooked) above that for water alone, in which the pressures are considerably below the theoretical.

VACUUM STUDIES.

The vacuum readings on cans used in the tests sealed at 70° and 80° C. are shown in Table 9.

TABLE 9.—*Vacuum tests with corn in No. 2 tin cans.*

Temperature (°C.).			Length of process (minutes.)	Barometer readings.		Vacuum (inches of mercury).
Sealing.	Processing.	After cooling.		At sealing.	After cooling.	
70	100	22¾	120	30.05	29.99	12
	116	25	110	29.99	29.86	9½
	121	17½	121	30.08	29.92	9⅞
80	100	25	140	29.56	29.62	15⅝
	116	24¾	120	29.99	30.01	14⅛
	121	24¼	120	30.01	30.05	13¾

As in tests upon other materials the higher the processing temperature the lower the vacuum, owing to the liberation of gases during processing. Repeated experiments have shown that for the same reason the longer the processing period the smaller the vacuum. All results are below the theoretical figures.

Vacuum readings with corn in No. 2 cans sealed in lots at various temperatures and processed intermittently for 1½ hours at 100° C. gave the figures shown in Table 10.

Concussion tests with corn prepared as in these vacuum tests showed that the susceptibility to denting gradually increased with the rise of sealing temperature. The figures obtained are also shown in Table 10.

TABLE 10.—*Vacuum readings and concussion tests with corn in No. 2 tin cans.*

Sealing temperature (°C.).	Vacuum (inches of mercury).	Fall of weighted can (cm.).
22	.....	8.0
45 to 50	3	8.9
55 to 60	7.6	8.6
65 to 70	11	7.6
75 to 80	14.6	6.4
95 to 100	21.2	5.0

These figures seem to indicate that sealing at initial temperatures as high as 85° C., or even higher, may be practiced without great danger of serious denting or collapsing of No. 2 tin cans.

Various influences tend to affect the results in individual cans—the weight of the tin plate from which they are made, the perfection in form, etc. The data shown in Table 10 represent an average for one lot of cans and are given for what they are worth.

HEAT PENETRATION.

The time-temperature relation for a No. 2 can of corn started at various initial temperatures, processed for various lengths of time under different retort conditions, and cooled in air and in water are given below.

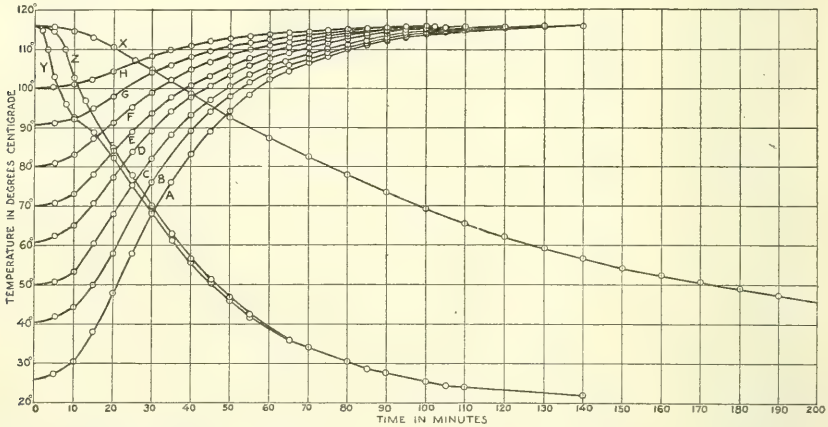

FIG. 21.—Experimental time-temperature curves for "Maine style" corn in No. 2 tin cans, starting at different uniform temperatures and processed at 116° C. Proportion of corn to liquor, 4 : 1. Curves are also given for cooling in air at 26° C. and for cooling in water at 20° C., one curve of which is for corn of heavier consistency. Curves for can starting: *A*, At 26° C.; *B*, at 40½° C.; *C*, at 50° C.; *D*, at 61° C.; *E*, at 70° C.; *F*, at 80° C.; *G*, at 90½° C.; *H*, at 100° C.; *X*, at 116° C. and cooled in air at 26° C.; *Y*, at 116° C. and cooled in water at 20° C.; *Z*, at 116° C. and cooled in water at 20° C., the consistency of the corn being heavier than that represented in curve *Y*.

Figure 21 gives the experimental heat-penetration curves for No. 2 cans of corn starting at various temperatures and processed at 116° C.

These show how differences in initial temperatures modify the form of the time-temperature curve. Theoretically, the temperature at the center of the can should reach the temperature of the retort in the same time for any initial temperature, but in these tests the cans starting at the higher initial temperature actually reached the temperature of the retort in a slightly shorter time. This would seem to be due to some convection occurring in corn of this consistency.

Thompson (9) has given a formula by means of which from a single experimentally determined heat-penetration curve one may

calculate corresponding curves for the different initial temperatures. A series of curves calculated by means of this formula, using one of the above experimental curves, will be found to agree closely with the other experimental curves starting at different initial temperatures. The formula is valuable in calculating curves of this sort in that it saves much time and labor.

Figure 21 also shows experimental curves for cooling both in air and in water. Attention is directed to the very slow rate of cooling in air as compared with that of cooling in water. The form of the curves for cans cooled in water are of special interest. In the case where the proportion of corn to liquor is the same as in the heating curve (that is, 4 to 1) the temperature falls very rapidly at first, but later the form of the curve becomes more regular and eventually coincides with the second curve.

In the corn of heavy consistency the lag at the beginning is greater, and the temperature falls more slowly. If the head space in the corn

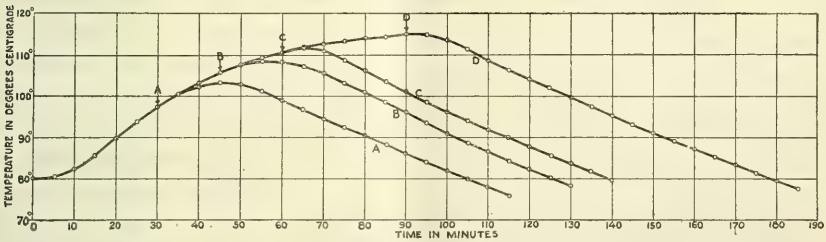

FIG. 22.—Experimental time-temperature curves for "Maine style" corn in No. 2 tin cans, starting at a uniform temperature of 80° C.; processed for different time periods at 116° C.; and cooled in air at ordinary room temperature. Proportion of corn to liquor, 4 : 1. The arrows indicate when cans were removed from the retort. Curve for can processed: *A*, For 30 minutes; *B*, for 45 minutes; *C*, for 60 minutes; *D*, for 90 minutes.

of heavy consistency is increased, the cooling will be faster and the curve will resemble closely that for the can of corn having a normal consistency. At temperatures above 100° C. and where the head space permits there seems to occur a condensation of steam in the head space, resulting in a simple sort of distillation which quickly reduces the temperature below the boiling point of water. The reduction of the pressure in the head space causes ebullition and a consequent stirring of the material, resulting in a rapid fall of temperature.

These results emphasize again the fact that cooling curves for food materials are practically never the exact reverse of the heating curves, even when temperatures of the surrounding medium are reversed.

Figure 22 shows experimental curves for No. 2 cans of corn sealed at 80° C. and processed at 116° for 30, 45, 60, and 90 minutes and then cooled in the air at 20° to 25° C.

These curves represent individual tests and hence probably vary somewhat from the average. They show how the temperature at the center of the can continues to rise after taking from the retort for from 5 minutes in the case of the can processed for 90 minutes to 15 minutes in the can processed for 30 minutes. They show, further, the length of time the corn remains above critical temperatures for sterilizing purposes. For instance, the temperature is seen to remain above 100° C. for 20 minutes when the processing is continued for 30 minutes and remains above 100° C. for 95 minutes when processed for 90 minutes. These values obviously would be different for curves starting at different initial temperatures. The curves give a definite idea, however, of the rate and the nature of the temperature changes when corn is processed for various periods and then air cooled. They show how very limited in value such curves as are illustrated in figure 21 may be, for they are a record of a continuous processing at a definite temperature until the temperature of the can reaches the temperature of the retort. Since with corn in actual practice the processing period is less than the time necessary for the can to reach the temperature of the retort, curves such as are shown in figure 21 give an actual record only so long as the can is in the retort, but tell nothing beyond that point. It is important to have a record of the temperature after the can is removed from the retort, which can be obtained best from curves made under conditions of actual practice. Since the behavior of the temperature of the contents of the can after removal from the retort varies with the processing period and with the cooling conditions, it makes the calculation of the record of one processing from another of a different length very difficult.

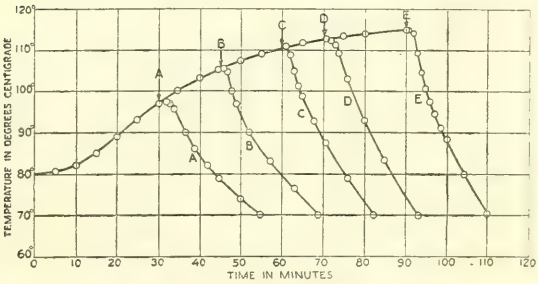

FIG. 23.—Experimental time-temperature curves for "Maine style" corn in No. 2 tin cans, starting at a uniform temperature of 80° C., processed for different periods of time at 116° C., and cooled in water at about 25° C. Proportion of corn to liquor, 4 : 1. The arrows indicate when cans were taken from the retort and put into water. Curve for can processed: *A*, For 30 minutes; *B*, for 45 minutes; *C*, for 60 minutes; *D*, for 70 minutes; *E*, for 90 minutes.

Figure 23 shows the time temperature curves for No. 2 cans of corn starting at 80° C., processed at 116° for 30, 45, 60, 70, and 90 minutes, and then cooled in water.

When the cans are removed from the retort and placed in cold water the rise in temperature is almost immediately stopped and the cooling curves drop rapidly. In corn, therefore, when the cans are

cooled in water the maximum temperatures are usually reached at the time when the cans are placed in the water. When cooling immediately in water is practiced one is able to control rather definitely the amount of cooking the corn will receive unless it is of very heavy consistency, when curves such as those shown in figure 21 may be of very much value.

The curves show that when the can is started at 80° C. and processed for 30 minutes at 116° the center of the can of corn never reaches 100° C. when cooled in water. When processed for 45 minutes it remains above 100° C. about 13 minutes, about 30 minutes when processed for 60 minutes, about 42 minutes when processed for 70 minutes, and about 60 minutes when processed 90 minutes. It remained above 110° C. for about 15 minutes when processed for 70 minutes, and for approximately 35 minutes when processed for 90 minutes.

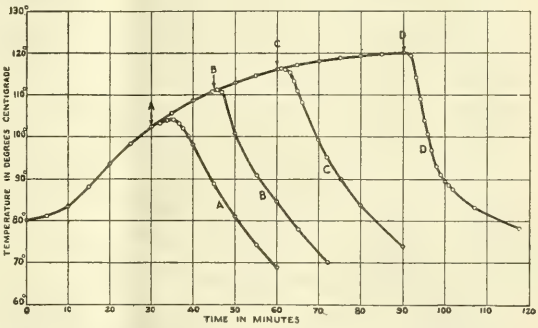

FIG. 24.—Experimental time-temperature curves for "Maine style" corn in No. 2 tin cans, starting at a uniform temperature of 80° C., processed for different time periods at 121° C., and cooled in water at 23° to 26° C. Proportion of corn to liquor, 4 : 1. The arrows indicate the time when cans were removed from the retort and placed in water. Curve for can processed: *A*, For 30 minutes; *B*, for 45 minutes; *C*, for 60 minutes; *D*, for 90 minutes.

Differences in initial temperatures and in the consistency of the corn, of course, would vary these figures.

Figure 24 shows similar curves for corn handled in the same way as in the above tests, except that the retort temperature of 121° C. was employed.

In the discussion of results obtained with string beans and peas the relationship of the time-temperature and the time-pressure curves was pointed out. In comparing the time-pressure and time-temperature curves in sweet corn it is seen that the pressure rises very rapidly during the first minute or two of the processing period, owing to the heating of the head space. On the other hand, the temperature at the center of the can is still little changed, and the heat certainly has penetrated only slightly into the material. After several minutes, however, the pressure rises more gradually, corresponding closely to the rate at which the heat penetrates into the material. It does not correspond exactly to this, however, for there is a continuous rise of pressure so long as the processing is continued, this being more pronounced with the higher processing temperatures.

SWEET POTATOES.

PRESSURE STUDIES.

In the tests upon sweet potatoes the material used was in the form of "pie stock," prepared by washing the potatoes, steaming until done, peeling, and then passing them through a food chopper to give a uniform consistency. The material was then weighed into the test cans, 600 grams being used in the No. 2 and 1,000 grams in the No. 3 can. After the can and contents were brought to a uniform desired temperature, the tests were performed in the usual way. Figure 25 shows the time-pressure curves for sweet potatoes in No. 2 cans sealed at the initial temperatures of 25°, 70°, and 80° and processed for 120 minutes at 116° C., and figure 26 shows the curves for No. 3 cans tested in the same manner.

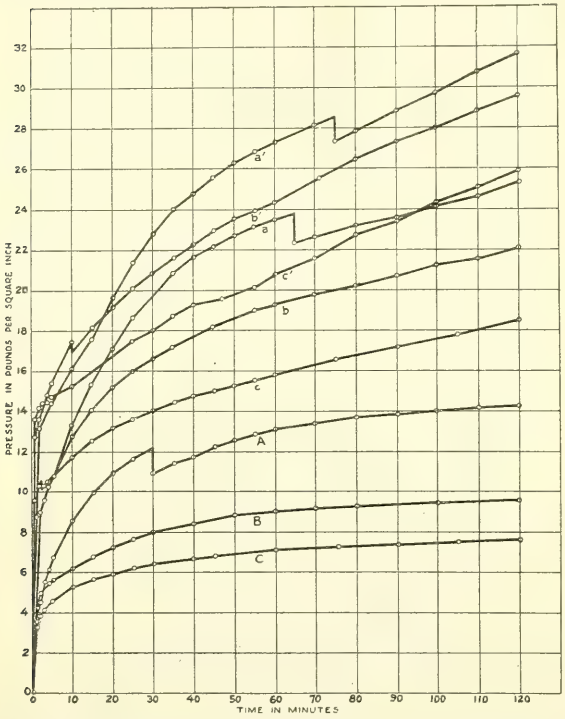

FIG. 25.—Experimental time-pressure curves for sweet potatoes in the form of pie stock in No. 2 tin cans, sealed at different uniform temperatures and processed for 2 hours at 100° C., 116° C., and 121° C. Curve for can sealed: *A*, At 25° C. and processed at 100° C.; *a*, at 25° C. and processed at 116° C.; *a'*, at 25° C. and processed at 121° C.; *B*, at 70° C. and processed at 100° C.; *b*, at 70° C. and processed at 116° C.; *b'*, at 70° C. and processed at 121° C.; *C*, at 80° C. and processed at 100° C.; *c*, at 80° C. and processed at 116° C.; *c'*, at 80° C. and processed at 121° C.

The outstanding features of the curves for sweet potatoes are much the same as for sweet corn.

The initial sudden rise in pressure does not reach so high a point as in the corn, owing to smaller head space. That this sudden rise is due to the expansion of the air of the head space is clearly shown by the fact that the curves following this initial rise begin their more gradual ascent at approximately the same point, later diverging according to the sealing temperature employed.

The rise in pressure continues throughout the processing period, corresponding in some degree to the rate of temperature change within the can, but not due entirely to this. The pitch of the curves

during this latter half of the processing period indicates that some influence other than increase of internal temperature is in operation. That this is the case is shown in the vacuum figures given later.

The maximum pressures attained vary in both directions from the theoretical, some being higher and others lower. The variable factors of sudden bulging and gradual distention of the cans, liberation of gases, etc., contribute to this result and account for it. The swelling of the starch can hardly account for any increase in pressure, as the material was well cooked before it was put into the cans.

The processing period used in these tests is longer for the higher temperatures than is commonly employed, but the maximum pressures for any period of 120 minutes or less will be shown on these curves, for when the steam in the retort is cut off the pressures fall almost immediately.

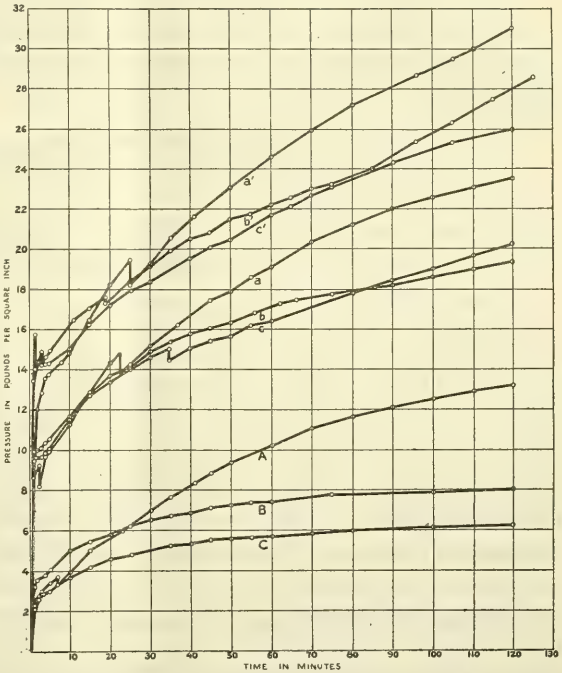

FIG. 26.—Experimental time-pressure curves for sweet potatoes in the form of pie stock in No. 3 tin cans, sealed at different uniform temperatures and processed for 2 hours at 100°, 116°, and 121° C. Curve for can sealed: *A*, At 25° C. and processed at 100° C.; *a*, at 25° C. and processed at 116° C.; *a'*, at 25° C. and processed at 121° C.; *B*, at 70° C. and processed at 100° C.; *b*, at 70° C. and processed at 116° C.; *b'*, at 70° C. and processed at 121° C.; *C*, at 80° C. and processed at 100° C.; *c*, at 80° C. and processed at 116° C.; *c'*, at 80° C. and processed at 121° C.

As pointed out in considering the results on string beans, the actual strain on cans at any time during the process may be found by subtracting the retort pressure from the pressure indicated for that time in the curve. The strain on the can is greatly increased when the retort pressure is released, but the greatest strain is felt when the pressure in the retort reaches zero. This amounts to only about 3 to 5 pounds less than the maximum pressure indicated in the curves, depending upon the temperature of sealing, the processing temperature, the bulging of cans, the rate of release of retort pressure, etc. If the retort pressure should be completely released instantaneously

the full maximum strains indicated in the curves would be exerted on the cans from within, but the gradual release of pressure allows some lessening from the maximum strain indicated. When the processing is done at 100° C. the maximum pressures indicated in the curves represent the actual strains on the cans. These curves illustrate again the necessity of sealing at relatively high temperatures.

VACUUM STUDIES.

Table 11 presents the results of vacuum readings on the No. 3 cans sealed at 70° and 80° C. used in the above tests when cooled to room temperature.

TABLE 11.—*Vacuum tests with sweet potatoes in No. 3 tin cans.*

Temperature (°C.).			Processing period (minutes).	Barometer readings.		Vacuum (inches of mercury).
Sealing.	Processing.	After cooling.		At sealing.	After cooling.	
70	100	10⅝	120	30.30	30.17	13⅞
	116	21	120	30.25	30.19	11
	121	13½	120	29.77	29.89	10⅝
80	100	16	120	29.98	29.86	14
	116	9	120	29.87	30.29	13½
	121	12	120	30.29	30.45	9

The figures in Table 11 do not differ essentially from those obtained with corn. They are below the theoretical, and there is the decrease of vacuum with the higher processing temperatures.

Concussion tests, as described under methods and apparatus, though not altogether satisfactory in point of uniformity of results, show that there is a relation between the vacuum and the susceptibility of the can to bruising in handling. The figures seem to indicate that in ordinary practice No. 2 cans may be safely sealed at as high as 85° C. Above 90° they are quite readily dented, and they usually collapse spontaneously when sealed between 95° and 100° C. Tests for the No. 3 cans show that they are much more easily bruised than the No. 2 cans where the vacuum is equal in the two cases. The results seem to indicate that it is scarcely safe to seal No. 3 cans very much above 80° C. Bruising occurs rather readily above 85° and the cans may collapse spontaneously at 90° C. or above, depending upon their strength.

HEAT PENETRATION.

The material used for the time-temperature studies in sweet potatoes was prepared in the same manner as that used in the foregoing experiments on pressure and vacuum. The rates of temperature changes in No. 2 cans of sweet potatoes, starting at different tem-

peratures and processed at 116° C., are shown in figure 27. Experimental curves for cooling both in air and in water are likewise given.

The heating curves are similar to those for corn, though there is a greater lag at the start and the temperature reached in a given unit of time is materially lower than in the corn. In other words, as has been previously shown, the rate of temperature change is slower in sweet potatoes than in corn, as ordinarily handled. Regardless of initial temperature, the temperature of the retort is reached in the same time.

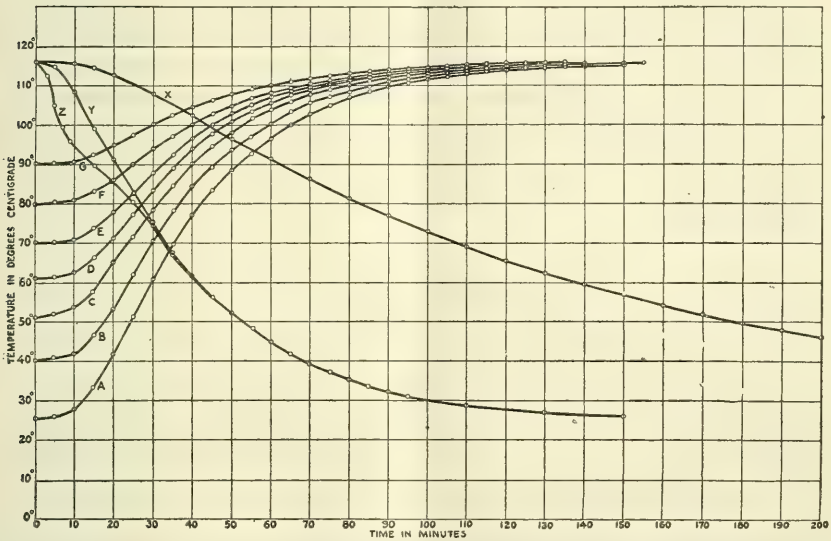

FIG. 27.—Experimental time-temperature curves for sweet potatoes in the form of pie stock in No. 2 tin cans, starting at different uniform temperatures and processed at 116° C. Curves are given also for cooling in air and in water at 26° C. A curve showing the effect of differences in head space upon the rate of cooling in water is included. Curve for can starting: *A*, At 25½° C.; *B*, at 40° C.; *C*, at 51° C.; *D*, at 61° C.; *E*, at 70° C.; *F*, at 80° C.; *G*, at 90° C.; *X*, at 116° C. and cooled in air at 26° C.; *Y*, at 116° C. and cooled in water at 26° C., head space very small; *Z*, at 116° C. and cooled in water at 26° C., head space three-eighths of an inch.

Here, also, as in the case of the curves for corn, the formula given by Thompson (9) for the calculation of curves for different initial temperatures from a single experimental curve is applicable, and the formula given by Bigelow and his collaborators for calculating curves for cans of different sizes may be made use of in time-temperature studies with sweet potatoes.

As has been pointed out in the consideration of time-temperature relations in corn, curves which require a longer time to reach retort temperature than that necessary to effect sterilization of the product are not safe guides in the determination of proper processing periods, inasmuch as when cooled in air and, in the case of sweet

potatoes, also when cooled in water, there is a continued rise of temperature at the center of the can for an indefinite period. Accurate information for this purpose must be obtained by processing for different periods and cooling in air and water, for which purpose the formulas of Thompson and of Bigelow are scarcely applicable.

The cooling curves are of interest in that they illustrate clearly the desirability of cooling cans of sweet potatoes in water. Owing to the high percentage of sugar in the sweet potato, caramelization is very pronounced when the processing temperatures are long continued, and it is desirable, therefore, that the processing period be carefully controlled. Air cooling, as shown by the curves, results in a slow fall of temperature, and the cooking is long continued. It must be rememered, however, that in slow cooling the sterilizing effect is continued for a longer period. How promptly the temperature falls when the can is cooled in water is illustrated by the other cooling curves.

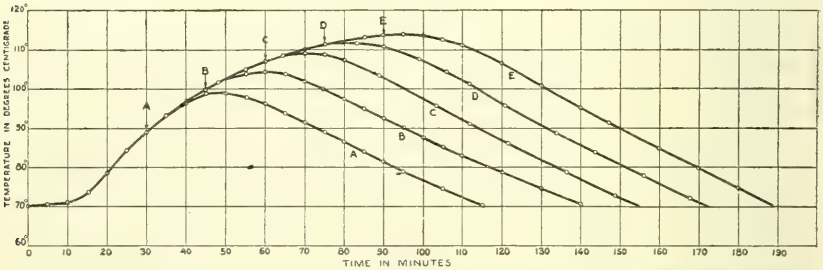

FIG. 28.—Experimental time-temperature curves for sweet potatoes in the form of pie stock in No. 2 tin cans, starting at a uniform temperature of 70° C., processed for different time periods at 116° C., and cooled in air at ordinary room temperature. The arrows indicate when the cans were removed from the retort. Curve for can processed: *A*, For 30 minutes; *B*, for 45 minutes; *C*, for 60 minutes; *D*, for 75 minutes; *E*, for 90 minutes.

Special attention is directed to the form of the curves for water cooling during the first 15 minutes. In the one case the curve is quite regular, while in the other there is a sudden drop in the curve, which later becomes more regular and eventually coincides with the first. The only difference in the conditions under which these tests were performed was that in the first case the can had a very small head space, while in the other a head space of about three-eighths of an inch was allowed. A similar condition was pointed out in the discussion on the cooling curves for corn where, also, the consistency was shown to be a factor. Owing to the heavy consistency and the necessity of filling the can almost completely, the cooling curves of sweet potatoes are more nearly the exact opposite of the heating curves than in any other substance tested.

In figure 28 are shown the experimental time-temperature curves for No. 2 cans of sweet potatoes, starting from a uniform initial tem-

perature of 70° C., processed at 116° for 30, 45, 60, 75, and 90 minutes, and then cooled in air at 26° C.

In the can processed for 30 minutes the temperature continues to rise for 20 minutes. A gradual reduction in the time during which the succeeding curves continued to rise is noted, the can processed for 90 minutes continuing only 5 minutes. In 30 minutes of processing the can did not reach 100° C. When air cooled the can processed for 45 minutes remained above 100° C. for 30 minutes; when processed for 60 minutes it remained above that point for a little over 50 minutes; when processed for 75 minutes, for about 70 minutes; and when processed for 90 minutes it remained above 100° C. for nearly 90 minutes. The significance of these figures is apparent.

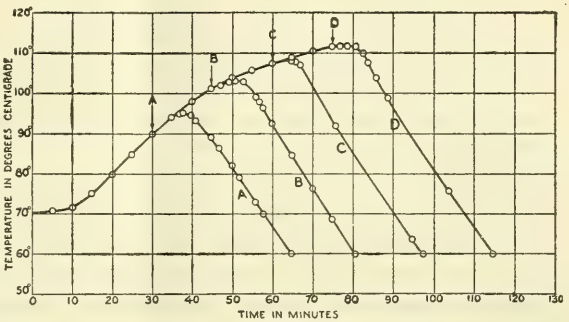

FIG. 29.—Experimental time-temperature curves for sweet potatoes in the form of pie stock in No. 2 tin cans, starting at a uniform temperature of 70° C., processed for different time periods at 116° C., and cooled in water at about 17° C. The arrows indicate when the cans were taken from the retort and placed in water. Curve for can processed: *A*, For 30 minutes; *B*, for 45 minutes; *C*, for 60 minutes; *D*, for 75 minutes.

Figure 29 shows curves obtained under like conditions, except that the cooling was done in water at 17° C.

It will be noted that with sweet potatoes, even in water cooling, the temperature continues to rise for a little while, but the time is much reduced over what was obtained with air cooling. Within the range of these experiments the rise continued only from 5 minutes in the case of the can processed for 75 minutes to 8 minutes in the can processed for 30 minutes.

As in the preceding figure, the temperature in the can processed for 30 minutes did not reach 100° C. at all; that processed for 45 minutes remained above 100° C. for about 12 minutes; that processed for 60 minutes for about 28 minutes; and that processed for 110 minutes for about 45 minutes.

Comparing these figures with the figures for air cooling, we find that the time during which cooking continues after 100° C. is reached is reduced by 18 minutes in the can processed for 45 minutes and by 25 minutes in the can processed for 110 minutes.

How one is able to control the cooking and thus prevent in a measure the caramelization of the material by water cooling of the cans is clearly illustrated.

Figure 30 shows the experimental time-temperature relations for No. 3 cans of sweet potatoes starting at the initial uniform tempera-

ture of 70° C.; processed at 116° C. for 30, 45, 60, 70, and 90 minutes, respectively, and then cooled in air.

The salient differences between these curves and those for No. 2 cans lie in the fact that the heat at the center of the No. 3 can con-

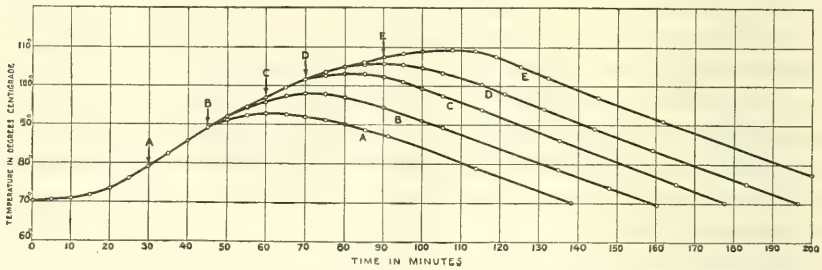

FIG. 30.—Experimental time-temperature curves for sweet potatoes in the form of pie stock in No. 3 tin cans, starting at a uniform temperature of 70° C., processed for different time periods at 116° C., and cooled in air at ordinary room temperature. The arrows indicate when the cans were removed from the retort. Curve for can processed: *A*, For 30 minutes; *B*, for 45 minutes; *C*, for 60 minutes; *D*, for 70 minutes; *E*, for 90 minutes.

tinues to rise for a longer time than in the No. 2 can, but the maximum temperatures attained are lower and the time the temperature remains above 100° C. in the various tests is materially less. This is due, of course, to the very slow rate of temperature changes in the sweet potato. The difference in time during which they remain above 80° C. is small, being slightly longer in the case of the No. 3 can.

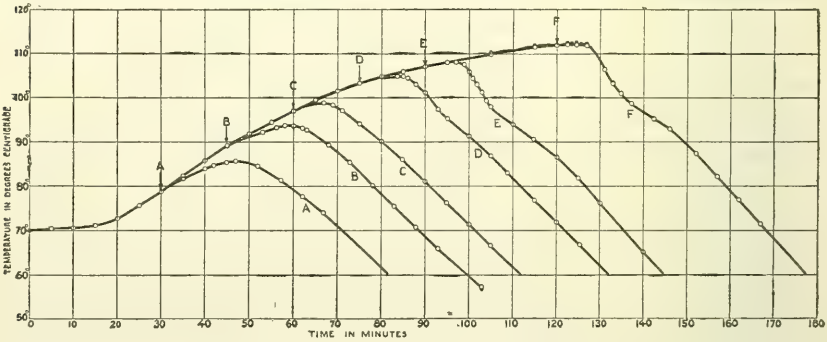

FIG. 31.—Experimental time-temperature curves for sweet potatoes in the form of pie stock in No. 3 tin cans, starting at a uniform temperature of 70° C., processed for different time periods at 116° C., and cooled in water at 16° to 20° C. The arrows indicate when the cans were taken from the retort and placed in water. Curve for can processed: *A*, For 30 minutes and cooled at 19° C.; *B*, for 45 minutes and cooled at 20° C.; *C*, for 60 minutes and cooled at 17° C.; *D*, for 75 minutes and cooled at 19° C.; *E*, for 90 minutes and cooled at 16° C.; *F*, for 120 minutes and cooled at 18° C.

Figure 31 shows the experimental curves for water cooling of No. 3 cans handled in the same way as the above.

As in the case of the No. 2 cans handled similarly, the temperature continues to rise after the cans are placed in cold water, but

the length of time is increased. In water cooling, even when processed for 60 minutes, the temperature never reaches 100° C. In addition to the facts brought out in the discussion on water-cooled No. 2 cans, the form of the cooling curves for No. 3 cans processed for the longer periods is of interest as illustrating again the effect of condensation of steam within the head space and the consequent rapid fall of temperature, which has been earlier considered. These, with the preceding curves, are of great practical value in determining the length of the processing period of sweet potatoes.

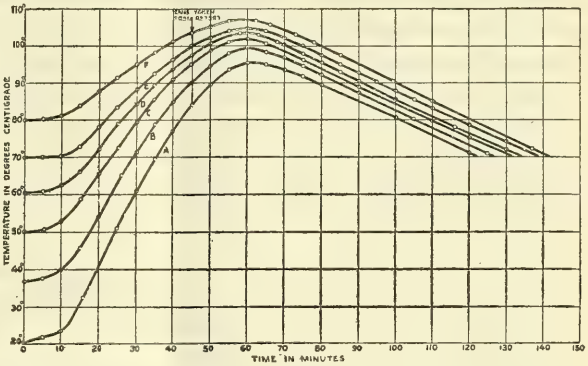

FIG. 32.—Experimental time-temperature curves for sweet potatoes in the form of pie stock in No. 2 tin cans, starting at different uniform temperatures, processed for 45 minutes at 116° C., and cooled in air at ordinary room temperature. Curve for can starting: *A*, At 20° C.; *B*, at 37° C.; *C*, at 50° C.; *D*, at 60¾° C.; *E*, at 70° C.; *F*, at 80° C.

Figure 32 shows the experimental curves for sweet potatoes in No. 2 cans, starting at the different initial temperatures, processed for

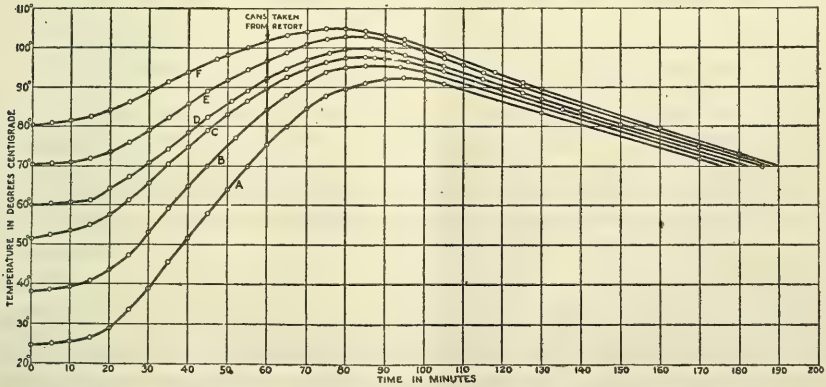

FIG. 33.—Experimental time-temperature curves for sweet potatoes in the form of pie stock in No. 3 tin cans, starting at different uniform temperatures, processed for 1 hour at 116° C., and cooled in air at ordinary room temperature. Curve for can starting: *A*, At 24½° C.; *B*, at 38¼° C.; *C*, at 51½° C.; *D*, at 60° C.; *E*, at 70¼° C.; *F*, at 80° C.

45 minutes at 116° C., and cooled in air. Figure 33 shows the same for the No. 3 can, except that the processing period is 60 minutes.

These curves show the effect which different initial temperatures have upon the maximum temperatures attained during a single definite processing period, and they furnish a definite picture of the

time-temperature changes which obtain under practical working conditions. They emphasize again the fact brought out in the earlier consideration of this subject that in substances where the processing period is shorter than the time required for the center of the can to reach the temperature of the retort, the entire heat penetration curves, like those shown in figure 27, are not safe guides for determining the length of the processing period and that the entire cooling curves as well do not illustrate working conditions. They show, further, that the maximum temperatures actually attained vary less with differences in initial temperature than might be expected from

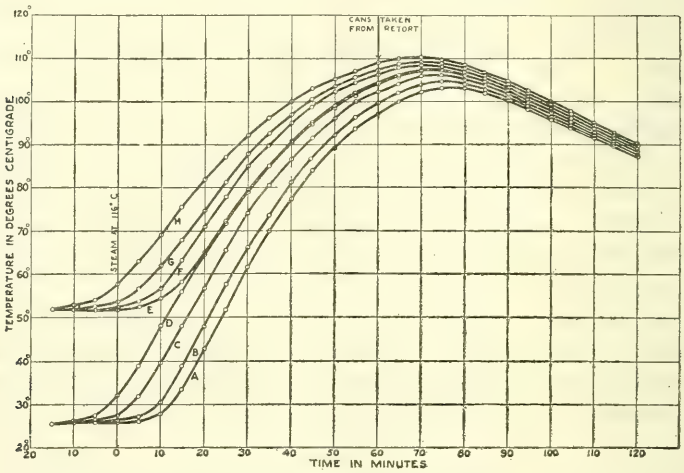

FIG. 34.—Experimental time-temperature curves for sweet potatoes in the form of pie stock in No. 2 tin cans, starting at different uniform temperatures, exhausted for different time periods at 100° C., processed for 1 hour at 116° C., and cooled in air at ordinary room temperature. Curve for can starting: *A*, At 26° C. and receiving no exhaust; *B*, at 26° C. and exhausted for 5 minutes; *C*, at 26° C. and exhausted for 10 minutes; *D*, at 26° C. and exhausted for 15 minutes; *E*, at 52° C. and receiving no exhaust; *F*, at 52° C. and exhausted for 5 minutes; *G*, at 52° C. and exhausted for 10 minutes; *H*, at 52° C. and exhausted for 15 minutes.

the curves in figure 21. Although the entire curve must be given consideration, certainly the most important part of this curve is when it is at its maximum. The fact that the maximum temperatures vary so very much less than the initial temperatures helps to explain why often such uniform results are obtained where considerable variation in initial temperatures exist. For instance, it will be seen, in the case of the No. 2 cans, that in cans starting at initial temperatures differing as much as 30 degrees, the maximum temperatures reached may not vary by more than 4 or 5 degrees, and in the case of the No. 3 can only slightly more.

The actual temperature reached and the length of time the material at the center of the can remained above any definite point may be readily observed.

Curves of this sort would vary in form and in the maximum temperatures reached, of course, with different retort temperatures and with the length of the processing periods.

In figures 34 and 35 are shown the effect of different exhaust periods upon the time-temperature curves for No. 2 and No. 3 cans of sweet potatoes sealed at different temperatures, processed for 60 minutes, and cooled in air. Exhausting was done in the steam box for 5, 10, and 15 minutes at 100° C.

The effect of exhaust upon the form of the curves and the maximum temperatures reached are clearly shown, and little comment is required. It may be pointed out that in the case of the No. 2 cans the temperature in all cases went above 100° C.; 15 minutes' exhaust resulted in the temperature remaining above 100° C. for 18 to 20 minutes longer than in those receiving no exhaust. The maximum temperatures varied by 4 or 5 degrees.

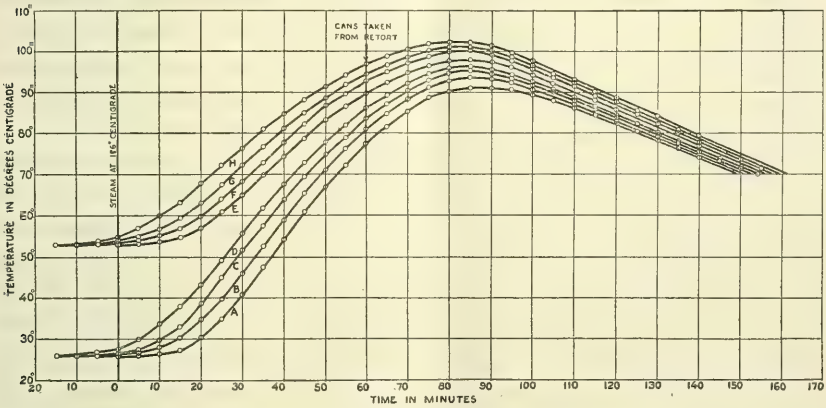

FIG. 35.—Experimental time-temperature curves for sweet potatoes in the form of pie stock in No. 3 tin cans, starting at different uniform temperatures, exhausted for different time periods at 100° C., processed for 1 hour at 116° C., and cooled in air at ordinary room temperature. Curve for can starting: *A*, At 26° C. and receiving no exhaust; *B*, at 26° C. and exhausted for 5 minutes; *C*, at 26° C. and exhausted for 10 minutes; *D*, at 26° C. and exhausted for 15 minutes; *E*, at 53° C. and receiving no exhaust; *F*, at 53° C. and exhausted for 5 minutes; *G*, at 53° C. and exhausted for 10 minutes; *H*, at 53° C. and exhausted for 15 minutes.

It is noted also that the time-temperature curve for the No. 2 can starting at 26° C. and exhausted for 15 minutes coincides almost exactly with that for the can sealed at 52° with no exhaust.

As is to be expected, the differences are greater in the case of the No. 3 cans. In only three of the cans did the temperature at the center of the containers reach 100° C. The maximum temperatures reached in cans exhausted for 15 minutes varied from those receiving no exhaust by 4 or 5 degrees, and, as in the case of the No. 2 can, the effect of the 15-minute exhaust on the increase in the length of time the temperature remained above a definite point amounted to 18 or 20 minutes.

SPINACH.

Owing to the limited quantity of raw material for use, the data upon spinach are incomplete. The figures which were obtained, however, are considered of sufficient value to warrant their use, and they are therefore presented for what they are worth.

The spinach was gathered fresh from the field, carefully trimmed, washed, and then blanched for two minutes in boiling water. It was then placed in the test cans, brought to the required uniform temperature, and the tests begun.

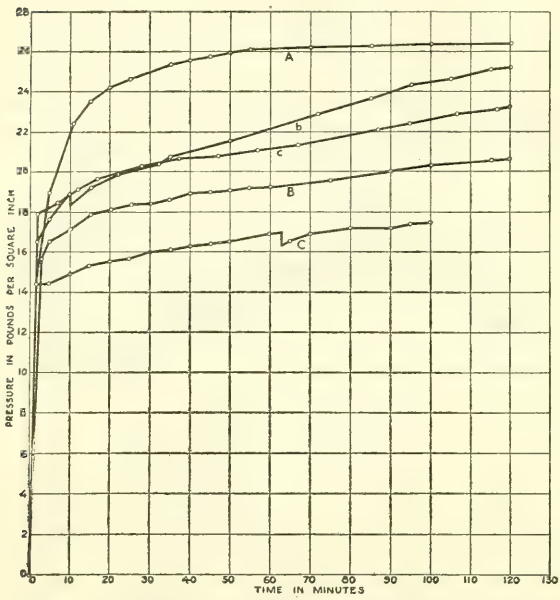

FIG. 36.—Experimental time-pressure curves for spinach in No. 2 tin cans, sealed at different uniform temperatures and processed for 2 hours at 116° and 121° C. Curve for can sealed: *A*, At 18¾° C. and processed at 116° C.; *B*, at 70° C. and processed at 116° C.; *b*, at 70° C. and processed at 121° C.; *C*, at 80° C. and processed at 116° C.; *c*, at 80° C. and processed at 121° C.

PRESSURE TESTS.

Figure 36 shows the curves for pressure tests with spinach in No. 2 cans, conducted as with other food materials already described.

The salient features of these curves do not differ from those shown in the tests upon corn. As in corn, there is a very sudden rise in the pressure curves, due to the sudden expansion of the air in the head space, after which the increase in pressure is more gradual. The continued increase in pressure is due apparently to the liberation of gases. In one case this was found to be still taking place at the end of more than three hours. Only one curve is given for cans sealed at low temperatures and none at all for the processing temperature of 100° C. That great reduction in pressure is obtained, however, by sealing at the higher temperatures is shown.

VACUUM STUDIES.

The vacuum tests upon spinach, while incomplete, as in the case of the pressure, bring out the following facts clearly:

(1) The vacuum obtained by sealing the spinach into the can at the desired temperature and then cooling immediately always gives a higher vacuum read-

ing than is obtained when the reading is made following processing. In the light of the preceding consideration of the liberation of gases during processing, this result is to be expected.

(2) The longer the processing period, the lower the vacuum obtained.

HEAT PENETRATION.

Figure 37 shows the heat-penetration curves for No. 2 cans of spinach starting at 70° and 80° C., processed for different periods at 116° and cooled in water. The entire heating curve is also shown for the No. 2 can, starting at 20° C. and processed at 116° until the retort temperature was reached.

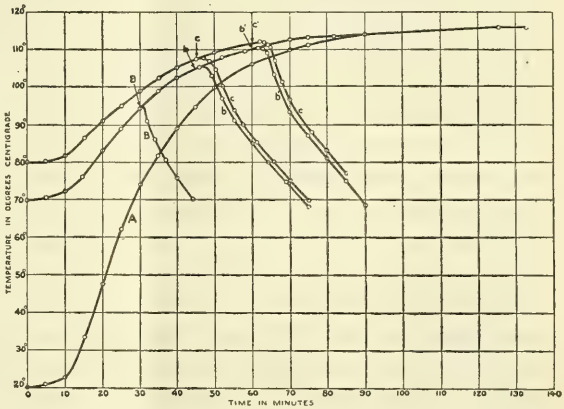

FIG. 37.—Experimental time-temperature curves for spinach in No. 2 tin cans, starting at different uniform temperatures, processed for different time periods at 116° C., and cooled in water at 23° to 24° C. The arrows indicate when the cans were taken from the retort and placed in water. *A*, Entire heat-penetration curve for can starting at 20° C. and processed at 116° C. Curve for can starting: *B*, At 70° C. and processed for 30 minutes; *b*, at 70° C. and processed for 45 minutes; *b'*, at 70° C. and processed for 60 minutes; *c*, at 80° C. and processed for 45 minutes; *c'*, at 80° C. and processed for 60 minutes.

These curves are entirely similar to those obtained for sweet corn, though the rate of temperature change is slightly faster.

By comparison of these curves with the entire curve, starting at 20° C., it will be seen that after 60 minutes of processing the temperature at the center of the can starting at 80° is only 6 degrees above that of the can starting at 20°, and in the case of the can starting at 70° C. it is only 4 degrees higher.

When the can is cooled in water the temperature at the center of the can continues to rise for one or two minutes only and then falls rapidly. It is obvious, therefore, that here also, as in the case of corn and sweet potatoes, the cooking of the material in the can may be closely controlled by cooling in water.

PRESSURE AND VACUUM IN GLASS CONTAINERS.

The studies upon pressure and vacuum as applied to foods in glass have not been completed. As is well known, the development of pressures in glass containers is accompanied by danger and loss, owing to liability to breakage, and this is avoided in present practice by partially sealing at first and then completing the sealing operation after the processing has been done. The escape of air, while nearly or entirely complete in most cases, may be slightly restricted

in others, so that small pressures are to be expected. The amount of pressure actually developed will depend, of course, upon the perfection in construction of the container, the thickness and quality of the rubber rings, and the pressure exerted by the device holding the cap in place. These pressures are practically negligible.

Investigations upon the resistance of rubber rings and other sealing equipment designed for use with glass are receiving attention at the hands of the manufacturers of glass containers, and Bitting (6) has recently published the partial results of work upon this subject.

The fact that with some substances an undesirable metallic taste is imparted to the food by the tin makes the use of glass containers desirable; and knowledge of the fact that, with fruits especially, delicate flavors may be retained in the product by completely sealing the jar before processing and then cooking at temperatures below 100° C. will doubtless lend impetus to investigations of this sort and result in the manufacture of glass containers better suited than those now employed for use where pressures are developed.

On account of their rigidity the pressures and vacuums obtained in glass jars hermetically sealed before processing should give figures more closely approaching the theoretical values than those obtained with tin. Owing to the fact that, in present practice, most, if not all, of the air escapes during the processing, the vacuum obtained is close to the theoretical value when the jars are sealed immediately at the end of the processing period. Unless complete sealing is effected at once, however, air is drawn into the jar and the vacuum obtained is less, depending upon the rate of cooling and the length of time elapsing before the jar is sealed.

SUMMARY.

(1) In tin cans containing various quantities of water, changes in pressure vary somewhat from the calculated values, owing to the distortion of the can under the changed conditions.

(2) With water the rate of change of pressure and the rate of change of temperature at the center of the can agree closely and are very rapid where the external medium is water and very slow where the external medium is air.

(3) With food materials in which a free liquid fills the interspaces the rate of change of pressure and of temperature is very rapid; but while the maximum temperature is reached promptly, the maximum pressure, on the other hand, is never reached during the ordinary processing periods, the pressure continuing to rise slowly as long as the high retort temperatures are maintained.

(4) In cans filled with material of heavy consistency, the rate of change of temperature at the center of the can is very slow. In contrast with this, the rate of change of pressure is very rapid at

first and then becomes slower after the first few minutes. An equilibrium of pressure apparently is never reached, since in experiments where processing was continued for several hours the pressure continued to rise as long as the retort temperature was maintained.

(5) The continued increase in pressure long after an equilibrium of temperature is reached has been explained as due to the decomposition of the food material with the consequent liberation of gases. The setting free of hydrogen as a result of the action of the acids of the material upon the metal of the can would give this result, and doubtless it does with some acid fruits, but experiments with vegetables seem to indicate that this is not the sole cause of the increase in pressure.

(6) In the heat exhausting of cans the vacuum may not be proportional to the average temperature of the material at the time of sealing, but is determined largely by the temperature of the head space. Thus, a short exhaust results in a comparatively high vacuum if the sealing is done immediately. On the other hand, a long exhaust may be very ineffective if the sealing is delayed so that the head space cools.

(7) The vacuum developed in tin cans is generally below the theoretical, the causes contributing to the variation from theoretical values being the distortion of the can, the swelling of colloidal substances, and the liberation of gases during processing. Lower vacuums are obtained where long processing periods are used and the higher retort temperatures are employed.

(8) The resistance of the can to internal pressure is very much greater than its resistance to external pressure; hence, the vacuum and the pressure can not safely be made numerically equal when processing much above 100° C. In order to reduce the strain due to internal pressure during processing, the sealing temperature is made as high as is possible without danger of collapse of the can in handling when subsequently cooled to normal temperature. The strain upon the can during processing is found by subtracting the pressure in the retort from that in the can. When the pressure in the retort is released the strain upon the can is increased by an amount somewhat less than the pressure in the retort, owing to the cooling which occurs during the release and to the further distortion of the can. The greatest strain upon the can occurs at the time the pressure in the retort reaches zero. The strain due to internal pressure is greater the lower the sealing temperature and the higher the processing temperature.

(9) The experimental work herein reported indicates that for most vegetables the optimum temperature for the sealing of No. 2 cans is 80° to 85°, and for No. 3 cans 75° to 80° C. This would be different, obviously, for fruits and other substances having high acidity and where the processing temperatures are low.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 1023

Contribution from the Bureau of Chemistry
W. G. CAMPBELL, Acting Chief

Washington, D. C. ▼ January 9, 1922

THE RELATIVE TOXICITY OF STRYCHNINE TO THE RAT.[1]

By Erich W. Schwartze, *Pharmacologist in Charge, Pharmacological Laboratory.*

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PURPOSE OF INVESTIGATION.

Strychnine, which heretofore has been regarded with little favor as a poison for rats, was selected as the second of a series of such substances to be studied in the Bureau of Chemistry. The work was designed primarily to ascertain the toxicological conditions under which strychnine will prove efficient and to determine the minimum amounts of this comparatively expensive drug which are required to kill rats.

RESULTS OF PREVIOUS INVESTIGATIONS.

The literature pertaining to the pharmacology of strychnine is very extensive, but only a few investigators have chosen the rat as an experimental animal. Allard (1)[2] cites Savory, who is said to have

[1] The experiments discussed in this bulletin constitute the second of a series dealing with substances employed as rat poisons. The first, on barium carbonate, was issued in 1920 as Department of Agriculture Bulletin 915.

[2] The figures in parentheses refer to "Literature cited," at the end of this bulletin.

killed a rat with 1 milligram of strychnine injected per rectum. Hunt [3] found the lethal subcutaneous dose to be 3 milligrams per kilo, and reported (12) that the toxicity of strychnine remained constant under thyroid feeding, a condition which appreciably influenced the susceptibility to some other substances. No references giving the oral lethal dose of strychnine were found, although many articles deal with its use as a rat poison. Rucker (21) states that poisoned grain is of little use because of its bitter taste. Boelter (3) says that "with a poison such as strychnine as the active ingredient, mice, as a rule, die on the spot, while rats die in their holes."

In a previous communication (23) it was shown that the efficient concentration of barium carbonate in a rat bait is equal to three times the lethal dose contained in a meal of average size. This method of calculation, however, does not seem to be applicable to strychnine at present, because of the fact that, according to previous investigators, rats refuse to eat bait containing it. It has been shown also (23) that soft, mealy food is consumed by rats more quickly than grain or dog biscuit. Whether or not the rapid eating of a bait has any practical significance other than to favor the chances for the ultimate consumption of a fatal dose of a particular strychnine bait apparently has yet to be determined.

PHARMACOLOGICAL ACTION OF STRYCHNINE.

The story of the action of strychnine is one of the most interesting in the field of comparative pharmacology. Although strychnine possesses the properties of a general protoplasmic poison, it is important chiefly for its marked selective action upon the central nervous system. Its ability to pervert the function of the segmental reflex mechanism is general in the case of all vertebrates thus far studied. The earthworm (13), the simplest form in which neurone synapses have been described, has also been shown to give the typical strychnine spasm. This perversion, frequently termed the abolition of reciprocal innervation (27), consists in the destruction of that function which permits the release of opposing muscles when certain other muscles perform a motion. Under the influence of enough strychnine, all musculature tends to contract simultaneously, producing a muscle-bound condition. The position assumed by the poisoned animals is that which results from the action of the stronger or sometimes the more advantageously situated sets of muscles.

While this perversion of function has been preserved in vertebrates throughout evolution, from time to time certain changes have

[3] Personal communication from Dr. Reid Hunt, Boston, Mass.

occurred. The size of the dose of strychnine required to produce death tends to decrease as the evolutionary scale is ascended. Unexplainable differences, however, are reported between the more closely related species such as rats and mice (Table 1). On the other hand, a low resistance to strychnine is found (25) in animals having a higher morphological type of pyramidal tract in the spinal cords (rabbits, cats, and dogs).

TABLE 1.—*Species tolerance to strychnine salts (minimum lethal and sublethal subcutaneous dose).*

Animal.	Usual sublethal dose, per kilo.	Usual lethal dose, per kilo.	Citation.
	Milligrams.	*Milligrams.*	
Rat	2.5	3.0 to 3.5	Table 4.
Do	2.0	3.0	Hunt (12).[1]
Mouse	.8	1.2	Do.
Do	.76	.77	Falck (6).[2]
Do		1.5	Page 14.
Guinea pig	3.4	3.41	Falck (6).[2]
Do	2.5	3.0 to 3.5	Hale (9).
Do		4.4	Hatcher and Eggleston (11).
Rabbit	0.4	.5	Hare (10).
Do	0.45 to 0.50	0.55 to 0.60	Meltzer and Salant (16).
Do		.57	Falck (5).[2]
Cat	0.35	.40	Cutler and Alton (4).
Do		0.32 to 0.384	Hatcher and Eggleston (11).[3]
Dog		0.35 to 0.42	Do.
Do	0.30		Hale (9).
Ground squirrel	0.6 to 0.7	0.7 upward.	Table 8.

[1] Personal communication from Dr. Reid Hunt.
[2] The salt administered by Falck was the nitrate. All other observers used sulphate.
[3] Hatcher and Eggleston (11) gave their dosages in terms of the alkaloid, but actually the sulphate was administered. The data given here have therefore been recalculated. The smaller dosages of these authors are for a solution containing 0.1 per cent of the alkaloid, the higher dose for 0.01 per cent solution.

The results from the type of experimentation shown in Table 1 are subject to fewer disturbing factors, so far as strychnine is concerned, than those from either the intravenous or gastro-intestinal methods of administration (11). These data, therefore, may be taken as representing the true species tolerance.

That the temperature of the environment also is an important factor is shown by the results of experiments on cold-blooded animals, in which it is easily possible to obtain a range of temperature amounting to 25° C. (29). Spasms occur more readily in frogs kept at 5° and at 30° C. than in those kept at 15° C. (7). The type of spasm also varies with the temperature. While frogs held at low temperatures have periods of long-continued tonic spasms, lasting sometimes for days, and separated by intervals of incomplete relaxation, those held at 30° C. undergo short spasms with more complete intervening relaxation. The short spasm, with practically complete relaxation, therefore, is the type observed in the homothermal, or so-called "warm-blooded" animals, which have a temperature-maintaining mechanism. Hibernation may directly affect the toxicity of and the behavior toward the drug, thus offering a possible explanation

of the discrepancies between the results of various observers (19), (30) on the hedgehog. Different batches of frogs sometimes vary in sensitivity toward strychnine. Neither the relation of this variation to the temperature and season nor the range between the convulsive and lethal doses has been determined.

The respective tolerance for any species of the adult homothermal mammals thus far studied has not varied markedly, the data reported in the literature by investigators who employed accurate methods agreeing very closely. Hunt and Seidell (12) have shown that while the tolerance of rats and mice to morphine varies with the dietary conditions, the toxicity of strychnine remains constant. Judging from the reliable data in the literature, no variation in the toxicity of strychnine caused by either diet or season occurs in other "warm-blooded" animals. In fixing the lethal dose, however, it would be advisable to perform many series of experiments, under suitable conditions, to rule out individual dietary and environmental factors.

Another modification which has occurred in the course of evolution is a tendency for a decrease in the number of spasms preceding death. Lower vertebrates, certain low mammals (24), and some very immature higher mammals (2), (5), (6), (15), (25) have multiple spasms preceding death. In certain immature mammals of the higher order a wide range between the convulsive and lethal doses exists. Very young animals are comparatively resistant to asphyxia and recover their ability to breathe more easily than mature members of the same species. On this account they can endure more successfully a large number of convulsions. This explanation, however, probably is not entirely adequate, for the reason that other characteristics differentiate the immature from the mature mammals here considered.

The size of the effective dose changes with the age of the mammals of certain species (25). At birth the mouse, rabbit, cat, and dog possess a natal immunity against the fatal action of strychnine, in this respect resembling the lower forms of animal life. Upon further development, however, this resistance is lost. After the decline of this resistance in the mouse a post-natal immunity, which reaches its limit about the time of sexual maturity, develops. The guinea pig also develops such a post-natal immunity, but, owing to its relatively mature state at birth, the decline of the natal immunity seen in other animals presumably is eclipsed by the period in utero. The cat, dog, and rabbit apparently develop no post-natal immunity, the adult lethal dose remaining at about the level to which the natal resistance declines.

Strychnine differs from many other poisons in that the body disposes of it very rapidly. The fact that small amounts of strychnine may appear in the urine for several days after its administration

does not necessarily signify a protracted period of danger or a marked increase in susceptibility of the individual to immediate subsequent poisoning. Hatcher and Eggleston (11), who have shown that the protective mechanism of the animal consists chiefly in the ability of the organism quickly to destroy this drug within the tissues, found the following coefficients of disposal, which are expressed in terms of the percentage per hour of a minimum subcutaneous lethal dose: For the cat, 12 to 25; for the dog, 14 to 17; and for the guinea pig, 18 to 57. These coefficients represent the conditions found when the strychnine is maintained somewhere in the neighborhood of the lethal concentration and not absolute hourly decrements when only a single subcutaneous lethal dose is given.

Under ordinary circumstances, in case of survival of the animal, strychnine is completely absorbed from the gastro-intestinal tract (12), but the exact rôle played by the stomach has not yet been determined. Although this organ is not endowed with general absorptive properties, it has been shown (22) that strychnine can be absorbed from the mucosa of Pawlow stomach fistulæ in dogs. However, a fatality from the administration of the minimum oral lethal dose of strychnine to an animal, such as a dog or cat, which usually has an empty stomach, in which the absorption of the entire dose is through the stomach mucosa, remains to be demonstrated. Nevertheless, it is possible that the absorption of the effective portion of the dose may occur in some instances chiefly or entirely through the gastric mucosa, particularly when the dose is very large.

TABLE 2.—*Relation of the oral to the subcutaneous lethal dose of strychnine sulphate.*

Animal.	Oral lethal dose per kilo.	Subcutaneous lethal dose per kilo.	Ratio.	Citation.
	Milligrams.	*Milligrams.*		
Guinea pig	[1] 44.0	[1] 4.4	[3] 10 to 1	Hatcher and Eggleston (11).
Rabbit	.....	.....	7 to 1	Nobecourt (18).
Cat	[2] 4.48	[2] 3.84	[2] 1.20 to 1	Hatcher and Eggleston (11).
Dog	[2] 5.4	[2] 4.6	1.20 to 1	Do.
Ground squirrel	.....	.....	[4] 5 to 1	S. E. Piper (17).

[1] Calculated from authors' data (Table 1).
[2] Calculated from authors' data, 0.0128 per cent strychnine sulphate solution used (Table 1).
[3] Approximate.
[4] Stomach to cheek-pouch ratio for poisoned grain.

In animals which can be obtained with empty stomachs, such as the cat and dog, the ratio of the oral lethal dose to the true species tolerance is very small, whereas in rabbits and guinea pigs, which have food continuously present in the stomach, it is extremely high. Presumably the rat would fall automatically into the second class, as the poison is to be administered in the food. This extreme point of

view must be taken to eliminate the influence of occasional adverse circumstances, such as food within the stomach ingested before the poisoned bait is eaten.

A large area of squamous mucosa occurs in the cardiac end of the stomach of the rat as a continuation from the œsophagus. If this has a favorable influence upon lowering the oral lethal dose it has not yet been shown. Such an influence should be considered, because much less strychnine is required to kill ground squirrels (*Citellus beecheyi*) when taken into the cheek pouches on grain[4] than when taken into the stomach either on grain or in solution.

Death from strychnine is due to asphyxia, which is the result of respiratory paralysis, the heart usually beating for some time after the spasms have abated. If a lethal dose has been given to an adult higher mammal, several spasms as a rule are sufficient. If the animal recovers from the initial spasm, it usually dies from a second or even a third. Instances of multiple and repeated attacks of spasms deserve investigation from the standpoint of their prevention by suitable environment. Life may be prolonged and sometimes saved by deep anæsthesia. Githens and Meltzer (8) obtained some recoveries from twice the lethal dose by the use of intravenous injections of Ringer solution, together with intratracheal insufflation. Presumably the advantage was double in that strychnine was eliminated at a relatively rapid rate in the urine on account of the diuresis and destroyed in the tissues at the usual rate. In the meanwhile the artificial respiration saved the life of the animal until the strychnine had been reduced below the absolute lethal amount.

Because of the relative suddenness of intoxication and the quick termination, remedial therapeusis in man ordinarily fails of an opportunity for use. Severe spasms in themselves are not necessarily a cause of death, as is shown by their occurrence in tetanus. Practically, however, it is possible to hasten death by producing them, or delay it, either by warding them off or by shortening them by the use of anæsthetics. For this reason therapists have recommended anæsthesia, together with absolute quiet. The reflexes resulting from the least noise or draft of air may inaugurate the vicious cycle of spasms.

On the other hand, the outcome in children, who are supposed to be more resistant than adults (28), seems less hopeless. A child (4) who apparently recovered after receiving an intraspinal injection of magnesium sulphate behaved in many ways like the infant animals. Even though lethal doses be administered to young animals, death is delayed. Life is prolonged thereby until suitable remedies

[4] Unpublished results of S. E. Piper, Bureau of Biological Survey, U. S. Department of Agriculture.

can be applied. Cutler and Alton (4) also successfully treated grown cats by the same method for exactly the minimum fatal dose of strychnine. The time element renders the practical application of this less favorable in adults than in infants. The use of magnesium sulphate is accompanied with some danger, which also precludes the use of this procedure unless previous experience in its application has been had.

EXPERIMENTAL PROCEDURE.

Throughout the course of this investigation strychnine has been considered from the angle of comparative pharmacology, the reason being that at some future time this drug may be more widely employed in poisoning animals than at present. Moreover, the relation of one species to another offers a more tangible basis for illustration than abstract data representing the lethal dose for rats. At the same time this is a very suitable plan from the aspect of the drug itself in that it has been used extensively as an experimental means in biology.

The brown and the white strains of *Rattus norvegicus*, as well as a few mice and ground squirrels (*Citellus richardsoni*), were employed for the experiments herein reported.

Two preparations of strychnine, one of free alkaloid and one of sulphate, tested and found to be free from brucin,[5] were used. The free alkaloid was passed through a sieve having 100 meshes to the inch. Two preparations of the adsorption combination of strychnine sulphate with diatomaceous or infusorial earth, found by the Kjeldahl analysis[6] to contain the amount of the alkaloidal salt stated on the label, were used. Standard 0.1 per cent strychnine sulphate solution was made up in physiological salt solution on the day of the experiments, lower dilutions being made as required from a freshly prepared 0.1 per cent solution. Thick cornstarch paste was taken to maintain a uniform suspension of the free alkaloid and of the infusorial-earth preparations. These suspensions were prepared in a small mortar, made up to volume in a 100 cc. volumetric flask by the starch paste and water washings from the mortar and thoroughly shaken. Amaranth, which in the concentration employed did not form a visible precipitate with strychnine, was used in some experiments for tracing the course of strychnine in the gastro-intestinal tract.

Injections into the stomach were made with a small hard-rubber urethral catheter, fitted over the outlet of a record syringe. The measurement of the starch-paste suspension therefore was by differ-

[5] H. E. Buc, formerly of the Bureau of Chemistry, made the tests.
[6] L. J. Jenkins, of the Bureau of Chemistry, made the analysis.

ence. Suitable amounts of starch-paste suspension containing the suspended alkaloid were driven into a Kjeldahl distillation flask through this tube by the syringe, and were found by analysis to contain practically the theoretical amount of nitrogen.[7]

Preliminary light ether anæsthesia was employed in all the stomach tube and in a few of the subcutaneous injection experiments. The anæsthesia passed off very soon. Subcutaneous injections were made under the skin of the abdomen. Young white rats of known age raised in the laboratory were used for testing the effect of age upon the size of the lethal dose of strychnine. All rats were put in small cages which were inverted to give the animals a better opportunity of grasping the wire netting with their toes. This procedure was adopted because it was found that rats kept in large cages sought the wire netting to endure their period of strychninization. Rats kept on metallic-sheet cage bottoms very easily lost their footing and had more frequent spasms. Autopsies were sometimes performed to ascertain the course of material injected, as well as the precision of some of the injections.

Table 3 gives data showing the relation of the alkaloid to its salts, as well as solubility data. Under some circumstances it might not be necessary to regard small differences in the percentage of strychnine in any one of its salts, but in this case it merits consideration.

TABLE 3.—*Relation of strychnine to its salts and their solubility in water.*

Preparation.	Molecular weight.	Contained strychnine.	Equivalent of strychnine sulphate.	Solubility in water.[1]
		Per cent.	*Per cent.*	
Strychnine sulphate	856	78	100	1 in 32.
Strychnine nitrate	397	84	108	1 in 42.
Strychnine alkaloid	334	100	128	1 in 6,420.

[1] U. S. Pharmacopœia, IX.

RESULTS OF EXPERIMENTAL WORK.

TOXICITY OF STRYCHNINE ADMINISTERED SUBCUTANEOUSLY.

The results of the subcutaneous administration of strychnine sulphate (Table 4) shows that the rat is exceedingly resistant to strychnine, being only slightly less immune than the guinea pig and very much more resistant than the rabbit, cat, dog, and ground squirrel (Table 1). The fact that the wild rat appears to be slightly more resistant than the white rat may be only apparent and due to the experimental error. The mortality in the white rat experiments, which make up Series F and which were performed on different

[7] L. J. Jenkins, of the Bureau of Chemistry, made the analyses.

days, varied from 20 to 50 per cent. The mortality from the experiments on wild rats (Series D and E) falls within this range. Moreover, the white rats received slightly larger doses, since they ordinarily possess much more body fat and have more material in the gastrointestinal canal than the wild rats in captivity. Moreover, the white rats used were raised under the best conditions, while the skin of wild rats frequently becomes thickened and tough, which may have had some part in delaying absorption of the drug.

TABLE 4.—*Toxicity of strychnine sulphate for rats administered subcutaneously in 0.1 per cent concentration.*

Series.	Rats.		Light anæsthesia.	Weight range.	Dose per kilo.	Survivals.	Fatalities.	Mortality.
	Number.	Kind.						
				Grams.	*Milligrams.*			*Per cent.*
A	8	Wild	Yes	140 to 290	2.0	8		
B	7	Wild	Yes	168 to 300	2.5	7		(1)
C	2	White	No	251 to 284	2.5	2		(1)
D	10	Wild	Yes	90 to 330	3.0	8	2	20
E	6	Wild	No	140 to 290	3.0	5	1	[2] 17
F	43	White	No	175 to 370	3.0	26	17	[3] 39
G	13	White	No	203 to 290	3.2	3	10	77
H	14	Wild	Yes	126 to 404	3.5	4	10	[4] 73
I	12	Wild	No	85 to 340	3.5	1	11	[5] 92
J	5	White	No	200 to 354	3.5	1	4	80
K	9	White	No	200 to 296	4.0		9	100

[1] No spasms occurred, but some animals were hyperexcitable.
[2] Only two rats had spasms.
[3] These animals were used for disposal tests, *vide infra*.
[4] Prespasm period, average 21 minutes; premortal period, 13 to 60 minutes, average 35 minutes.
[5] Prespasm period, average 17 minutes; premortal period, 17 to 55 minutes, average 33 minutes.

It is not evident that preliminary transient etherization played any rôle in the prevention of fatalities. While there is a slight difference in the total percentages between Series H and I, the other experimental data of those succumbing in both series show a remarkable agreement. Series D and E showed the reverse, the mortality being practically the same, but not the time relations.

The only way to reconcile these slight differences is by regarding the experimental error as sufficient to deceive the experimenter unless he guards against a too strict interpretation of numerical data. This factor of etherization was tested for the purpose of serving as a control to the stomach tube experiments, in which it was necessary to employ this preliminary step. These experiments show that etherization does not exert a lasting effect. If etherization is to be used therapeutically, therefore, it should be tried simultaneously with the appearance of spasms.

Under the conditions of the experiments the usually certain lethal dose is fairly constant and lies, within a narrow range, between 3 and 3.5 milligrams per kilo. The results obtained in experiments

elsewhere reported, in which the cages were not inverted, were much less concordant. As a further test, several rats were shaken from the sides of the cages to which they were tightly holding, with the production of fatal spasms. These observations on the rat seem to be in harmony with the fact that but few investigators have mentioned the conditions under which their animals were kept during the experimental period. Different conditions of experimentation may account for a variation in the size of the minimum lethal dose and the occurrence of convulsions from a sub-lethal dose. No tests were made, however, on other species for the purpose of reproducing some of the inconcordant data in the literature. Although rabbits, guinea pigs, and dogs are unable to grasp as well as climbing animals (cats and rats), it would seem advisable in all cases to select an environment offering the opportunity obtaining in nature.

Since it is possible to produce or hasten death by producing spasms, a few experiments were conducted to see if life could be prolonged by enforcing quiet. Several rats were given 4 milligrams of strychnine sulphate per kilo and placed on a slippery glass plate. In due time a sudden jump in the air and violent tonic convulsions resulting in death occurred. Previously the rats had stood practically motionless except for the movements of respiration. These results show the impracticability of securing survivals from more than a lethal dose by maintaining a volitional but forced quiet, because uncontrollable and involuntary motions will occur and start the vicious cycle of convulsions. Nevertheless, adult rats may be more or less influenced by the environment of and procedures resorted to in the experiment, and low results may be obtained.

In the experiments which were performed at various times in the year and on rats on different diets, no variation in the size of the lethal dose which could be assigned to dietary seasonal influences was obtained.

TOXICITY OF STRYCHNINE ADMINISTERED ORALLY.

Tables 5 and 6 show the results of administering strychnine sulphate and strychnine alkaloid orally.[8] The attempt to obtain rats with food in the stomach was not always successful, particularly in the case of wild rats. While some fatalities presumably were caused indirectly by the absence of food from the stomach, as well as by accidentally forcing the injected material beyond the pyloris, this error is automatically ruled out when the percentage of deaths is near the maximum. The data in the two tables agree in general, in

[8] For various reasons it was not feasible to depend upon feeding experiments. The reliability of the stomach tube as a means to obtain accurate data was shown in a previous report (23).

that from 20 to 25 milligrams of strychnine alkaloid or its equivalent in the alkaloidal salt is required to insure a large percentage of fatalities.

TABLE 5.—*Toxicity of strychnine sulphate administered in solution by stomach tube to lightly anæsthetized rats.*

Number of rats.	Kind.	Weight.	Strychnine sulphate solution.	Dose received, per kilo.	Survivals.	Fatalities.	Mortality.
		Grams.	*Per cent.*	*Milligrams.*			*Per cent.*
13	Wild	120 to 406	0.1 to 1.0	2.8 to 6.0	13	0	0
14	Wild	66 to 362	1.0 to 1.0	10.0	9	5	35
13	Wild	60 to 334	.5 to 1.0	15.0	4	9	69
13	Wild	46 to 370	.5 to 1.0	20.0	3	10	77
4	Wild	148 to 220	1.0	25.0	1	3	75

TABLE 6.—*Toxicity of strychnine (alkaloid) administered by stomach tube to lightly anæsthetized rats as 1 per cent suspension in starch paste.*

Number of rats.	Kind.	Weight.	Dose received.		Survivals.	Fatalities.	Mortality.
			Strychnine alkaloid, per kilo.	Calculated as strychnine sulphate, per kilo.			
		Grams.	*Milligrams.*	*Milligrams.*			*Per cent.*
26	Wild	110 to 404	7.5 to 12.0	9.6 to 15.4	11	15	58
4	White	132 to 205	10.0	12.8	3	1	25
5	White	172 to 208	15.0	19.2	1	4	80
18	Wild	84 to 385	15.0	19.2	3	15	83
15	Wild	62 to 360	20.0	25.6	1	14	93
9	Wild	160 to 473	25.0	32.0	0	9	100

TOXICITY OF DIATOMACEOUS EARTH PREPARATIONS OF STRYCHNINE.

The results of the administration by stomach tube of strychnine sulphate combined with diatomaceous earth (so-called tasteless preparation of strychnine) appear in Table 7. In this adsorbed form and concentration the toxicity of strychnine was reduced more than 50 per cent.[9] Since the alkaloid in this combination is not known to be liberated in an acid medium, it probably was not liberated in the stomach. Obviously diatomaceous earth would be an imperfect antidote for strychnine poisoning on account of the uncertainty of its opportunity to become attached to previously ingested strychnine, as well as the uncertain stability of the substance when formed.

[9] These results were obtained with preparations containing from 6 to 8 per cent of strychnine sulphate. It is possible, however, that much larger quantities of strychnine could be placed in preparations of this type, with no practical effect upon their palatability, but with an increase in the potency of the strychnine actually present. This possibility may be explained by the supposition that the ease of liberation of the strychnine in the beginning is greater when large amounts of strychnine are present.

The only conceivable advantages in the use of a preparation of this sort are its highly probable nonabsorption in the stomach, and the absence from it of taste. Presumably the rat would receive no immediate physiological warning, since no strychnine would be liberated to be absorbed by the stomach. The amounts which would be surely lethal, however, are large and the cost of the commercial article is so great that the practicability of its use for rats is open to question at present.

TABLE 7.—*Toxicity of strychnine sulphate diatomaceous earth preparation to wild rats.*

Number of rats.	Weight.	Dose of strychnine sulphate per kilo.[1]	Survivals.	Fatalities.	Mortality.
	Grams.	*Milligrams.*			*Percent.*
8	126 to 328	10	[2] 8		
2	186 to 192	20	[3] 2		
5	105 to 360	25	[4] 4	[4] 1	20
2	130 to 136	35		[5] 2	100
2	234 to 300	40	1	[5] 1	50
9	93 to 300	50	4	[6] 5	55

[1] Material was suspended in starch paste so as to contain 1.0 per cent of the alkaloidal salt.
[2] Only 2 were spastic.
[3] Both were nervous.
[4] All were spastic.
[5] Fatalities occurred after second hour.
[6] Five died within 24 hours.

EFFECT OF AGE OR DEVELOPMENT UPON TOXICITY OF STRYCHNINE.

In experiments reported elsewhere (25) it has been shown that as the rat develops it passes through stages indicating in a functional way the development of its nervous system. Early during the nursing or crawling stage the tolerance to strychnine is high. There is also a latitude between the minimum convulsive and the minimum lethal subcutaneous dose. By the time the animal acquires some physical dexterity the lethal dose falls to about the level of the convulsive dose. These rats then have only a few spasms preceding death, while in the crawling stage when a lethal dose is administered many spasms usually occur. About the time the rat is capable of beginning an independent existence (25 days) the resistance begins to rise, and ordinarily no convulsions occur until the lethal dose is reached. The highest subcutaneous dose survived by the rats in the crawling stage is 2 milligrams per kilo. Just after this stage is passed (in the weaning stage) the lethal dose is approximately 0.5 milligram per kilo. At about the time of sexual maturity it is 3 milligrams per kilo, or six times that of the weaning stage tolerance.

DISPOSAL OF STRYCHNINE.

In a series of experiments reported in detail elsewhere (26), it was found that the rat can always dispose of 33 per cent of a minimum lethal subcutaneous dose of strychnine in two hours; that about half

of the rats can dispose of 50 per cent; and that only rarely does one successfully dispose of 67 per cent. This was determined by injecting a series of rats with the minimum lethal subcutaneous dose, and at the end of two hours injecting those surviving with one of these fractional doses.

Coefficients of this magnitude are representative of the experimental conditions obtained when the drug is maintained somewhere near the lethal concentration, because strychnine may be found in the urine of various animals for several days after similar injections are made. Coefficients obtained in this manner, therefore, apparently can be applied only on a relative basis. To illustrate: The average coefficient of disposal is 50 per cent the first two hours. The amount disposed of the second two hours is presumably only 50 per cent of the 50 per cent which remained at the end of the second hour. At the end of the fourth hour, if the application of the coefficient were by absolute amounts, no strychnine would be left, whereas on a strictly relative basis 25 per cent would still be present. For this reason halving the coefficients obtained for 2-hour periods probably gives results slightly low for the first hour. The data, nevertheless, illustrate the marked ability of the rat to withstand this drug, providing the maximum sublethal concentration is not exceeded. An average rat, however, can eliminate a minimum lethal subcutaneous dose with certainty in four hours (26) and presumably in three hours, if the amount of strychnine is continuously kept near the lethal concentration.

Because of this rapid disposal it is possible for the rat to survive many times the lethal subcutaneous dose when it is administered by mouth, providing the amount present within the system at any one time does not exceed the maximum sublethal dose. This also explains why some animals (28) are extraordinarily resistant to strychnine by mouth. In comparing the oral toxicity of strychnine in one species of animals with that in another, ratios of potency of from 1 to 50, or even from 1 to 100, may be obtained. Analysis will show that the reason for so high a ratio may be that one of the animals used for the comparison is very sensitive and has an empty stomach, thus requiring only a small oral dose, while the other has a full stomach, retarding the absorption of the strychnine and increasing from 5 to 10 times the originally high species tolerance. Ratios of potency of this magnitude, therefore, must be considered as practical ratios only, rather than as the true indices of species resistance.

ABSORPTION FROM STOMACH.

In considering previously the absorption of strychnine from the stomach, the question of distinguishing between absorption by the stomach of a lethal dose of strychnine in the absence of food and in

the presence of food was raised. By using amaranth, which did not form a precipitate with strychnine in the concentration in which it was used, it was possible to trace the course of strychnine down the gastro-intestinal canal. In some instances the dye had penetrated into the duodenum or very close to the pyloris; in others the antrum of the stomach was filled by well-packed, semidry contents, the dye being in the cardiac and midportions of the stomach. Death in the second case must have been due to absorption directly through the stomach wall. The possibility that the food filtered out the coloring matter as the strychnine solution progressed seems untenable because of the remoteness from the pyloris and the fluid character of the dyed material in contrast with the semidry material in the antrum. Practically it would appear to make little difference whether death ensued by sufficiently accelerating or forcing a gastric absorption by a high concentration or by permitting a small amount to enter the small intestine, or by a combination of both. These results do not indicate a marked absorption of strychnine in the stomach, although death may ensue when the dose administered is very much greater than the subcutaneous lethal dose.

RELATIVE TOXICITY OF STRYCHNINE TO GROUND SQUIRRELS, MICE, AND RATS.

Table 8 shows the results of experiments on ground squirrels (*Citellus richardsoni*), the minimum subcutaneous lethal dose being 0.7 milligram per kilo. The data show also that the ground squirrel is four or five times more susceptible to the poison administered subcutaneously than the rat. This is one of the two pharmacological reasons which make the successful poisoning of the rat more difficult. The case of ground squirrels differs somewhat from that of rats, since it has been shown by Piper (17) that the poison is absorbed from the cheek pouches and that the lethal dose is also much less by this route than by the stomach. The range between the highest dose of strychnine survived and the lowest lethal dose in the experiments reported by Pierce and Clegg (20) for California ground squirrels (*Citellus beecheyi*) is so great that no accurate comparison of their data with those here reported can be made.

According to Falck (6), the toxicity of strychnine administered subcutaneously to the mouse is about four times greater than that here reported for rats. According to Hunt's data (Table 1) it is about two and five-tenths times more toxic. In the experiments herein reported large white and wild mice were tested with the same technique as that used for rats. It was found that 2 milligrams of strychnine sulphate per kilo injected subcutaneously proved fatal, 1.5 milligrams being somewhat less certain. For these particular mice strychnine was about half as toxic as it was for rats.

The lethal dose per os was approximately three to five times the subcutaneous dose. Both the subcutaneous and oral experiments bore out the inference to be drawn from Boelter's statement (3) that when administered orally it usually acts more quickly in mice than in rats. Owing to the great number of experiments required and the inability to obtain very large specimens, no attempt was made to study the effect of size, strain, and experimental technique upon the toxicity of strychnine to mice. Undoubtedly, however, the mice which have thus far been tried are more susceptible than rats and apparently they should be three or four times as easy to poison as rats.

TABLE 8.—*Toxicity of strychnine sulphate administered subcutaneously to male Richardson ground squirrels (Citellus richardsoni).*[1]

Date.	Weight of squirrel.	Strychnine sulphate solution injected.			Result.
1920.	*Grams.*	*Per cent.*	*Cc.*	*Milligram per kilo.*	
Aug. 6	160	0.05	0.32	1.0	Fatal spasm began in 28 minutes; dead in 30 minutes.
Sept. 8	280	.02	1.25	.9	Fatal spasm began in 11 minutes; dead in 12 minutes.
Do	339	.02	1.18	.7	Several mild spasms; partial ability to recover; dead in 18 minutes.
Aug. 6	184	.01	1.29	.7	Hyperexcitability only; lived.
Do	240	.01	1.44	.6	Lived.
Do	190	.01	.95	.5	Do.

[1] Acknowledgment is due Vernon Bailey, of the Bureau of Biological Survey, for procuring these animals.

STRYCHNINE BAITS.

White rats were given 1 per cent strychnine bait in the form of soft, mealy food containing about 20 per cent of fat. These rats were accustomed to such a diet, without the strychnine. That the bait was distasteful to them was evident from the way they rubbed their mouths on the floor and sides of the cage. Within about 15 minutes most of the rats were unusually excitable and some had sought the wire netting on the sides of the cages for support, indicating that part of the strychnine bait had been consumed and strychnine absorbed.

Obviously this muscle tenseness and excitability might cause the animal to become suspicious and cease eating. Strychnine baits of a type favoring rapid consumption are preferable. Although the food was left in the cages for more than 18 hours, only a few rats died. These results agree with those of practical tests showing that strychnine bait is not well eaten by rats. So much of the food was scattered that no attempt was made to estimate that which remained uneaten.

In a previous communication (23) it was shown that the average size of the meal consumed by hungry white rats was one one-hundredth of their body weight. Good practical poisoning results were obtained with barium carbonate by putting three times the amount necessary to kill (20 per cent) in the bait. If one-third of the average meal were consumed a fatal dose would be ingested. On this basis the efficient percentage of strychnine in a rat bait should be 0.75 per cent, or 1 part in 133 parts of bait. This concentration will be useful in the preparation of baits that are tasteless and rapidly consumed. Practically, however, it may be found that more strychnine will be required if such baits are not consumed quickly, or if the potency is decreased.

Table 9 gives a list of baits, worked out by practical tests, which seem to contain a very liberal amount of strychnine for all animals other than the rat. The rat, however, is five or six times more resistant to strychnine administered subcutaneously (Table 1) than the ordinary domesticated rabbit. If these data for the domesticated rabbit are representative also for the jack rabbit, the liberality with which this animal has received strychnine in its bait and the shortcomings of the rat bait will at once become apparent. The rat baits contain on the average but little more strychnine than the jack rabbit baits. The ground squirrel (*Citellus richardsoni*) is four or five times more sensitive to strychnine than the rat (Table 8). These animals are killed by relatively much less strychnine because strychnine is far more potent by way of the cheek pouches than when taken into the stomach. The difference between the concentration of strychnine in the ground squirrel baits and that in the rat baits, however, is not as marked as might be expected.

TABLE 9.—*Types of strychnine bait used for poisoning animals.*

Bait.	Strychnine.		Animal.	Equivalent or approximate amount of strychnine sulphate in dry bait.		Citation.
	Form in which added.	Ultimate form.		*Parts.*	*Per cent.*	
Barley	Sulphate	Sulphate	Ground squirrel.	1–480	0.21	Merriam (17).
Milo maize	Alkaloid	Alkaloid	Prairie dog	1–290	.35	Bi. 158.[4]
Do	Sulphate	do	do	1–370	.27	Bi. 158.
Do	do	do	do	1–360	.28	Bi. 163.
Alfalfa	do	Sulphate	Jack rabbit	1–257	.39	Bi. 163.
Milo maize	Sulphate or alkaloid.	Alkaloid	do	1–366 to 1–262	0.3 to 0.38	Bi. 163.
Barley	Sulphate	do	Ground squirrel.	1–290	.345	Pierce and Clegg (20).
Rolled oats	do	Sulphate	Rat	1–170 to 1–210	[1]0.59 to 0.48	Lantz (14).
Wheat	do	do	do	1–200	[2].50	Do.
Do	do	do	do	[1]1–400	[3].25	Rucker (21).

[1] Somewhat less on moisture basis.
[2] Estimate liberal.
[3] Allowing for presumable typographical error in original article; estimate liberal.
[4] "Bi." refers to mimeographed circular letter giving directions for making baits, issued by the Bureau of Biological Survey, U. S. Department of Agriculture.

SUMMARY.

The limit of tolerance of *Mus norvegicus*[10] to strychnine administered subcutaneously is from 3 to 3.5 milligrams of strychnine sulphate per kilo. Of the comparatively few species of mammals for which accurate data are available, the guinea pig alone possesses a resistance greater than this. The existing data indicate that while the lower orders of mammals, such as the Chiroptera (bats) (24) and Insectivora (hedgehog) (19) (39), are at times more tolerant than the guinea pig and the rat, at other times they are less tolerant.

The size of the subcutaneous lethal dose (species tolerance) remains constant when a certain definite experimental procedure is followed. General or mixed diets and seasons had no effect upon the species tolerance in the series of experiments reported in this bulletin.

The rat shows a marked ability to dispose of strychnine. Under favorable conditions the calculated disposal amounts to 1 milligram per hour (one-third of a minimum lethal subcutaneous dose). Practically, with the unfavorable experimental procedure used (discontinuous injections) it was slightly less than this.

Immature rats differ from adult rats, both in the toxicity of and reaction to strychnine, which seems to be correlated with the functional development of their nervous system.

The practically certain oral lethal dose of strychnine is from 20 to 25 milligrams per kilo of the free alkaloid, equivalent when calculated as the sulphate to from 25.6 to 32 milligrams. The ratio of the subcutaneous lethal doses to the oral lethal doses is about 1 to 8 or 1 to 9. The reason for this high ratio in rats would seem to be that when less than a lethal dose has been given the stomach and its contents directly or indirectly hinder absorption. On this account the animal can prevent the accumulation of a lethal amount within the system by the rapid disposal. When a lethal dose is administered by mouth the fatality usually occurs within several hours. The rat, therefore, must be overwhelmed by the drug; otherwise, it probably will survice. At times this certainly involves the play of a usually subordinate function, gastric absorption.

On the basis of its alkaloid content, the toxicity of two so-called tasteless preparations of strychnine (adsorption compound of diatomaceous or infusorial earth with strychnine sulphate) was found to be reduced by more than 50 per cent.

Mice are more susceptible to strychnine than rats, both to subcutaneous injections and to doses orally administered.

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[10] It is to be hoped that the first opportunity presenting itself for a comparative test with *Mus rattus* will be accepted by those into whose hands these data fall. The supposition that the toxicity of strychnine will be the same in both cases is not warranted, although it is legitimate to infer that this is true in the case of barium carbonate.

Ground squirrels (*Citellus richardsoni*) are about four or five times more sensitive to strychnine administered subcutaneously than rats. This helps to account for the comparative difficulty in poisoning rats.

The percentage of strychnine which would make a successful rat bait can not be stated at present. After the factors of rapid consumption and palatability are solved, it should be possible to obtain good results with 0.75 per cent of the alkaloid in potent form in the formula. This percentage represents three times the fairly certain fatal dose in a meal of the average size. It is probable that any success obtained with lower concentrations represents instances of fatalities from amounts smaller than can always be considered certain or from larger amounts of bait than can always be relied upon to be eaten. Experiments herein represented should be continued, employing feeding tests with perfectly palatable strychnine baits, in order to determine how rapidly strychnine is absorbed from the particular bait. Since the absorption may be very rapid, an increase in the percentage of strychnine here given may be found expedient, even though the bait is eaten fairly rapidly.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 1024

Contribution from the Bureau of Animal Industry
JOHN R. MOHLER, Chief

Washington, D. C. February 10, 1922

FEEDING EXPERIMENTS WITH GRADE BEEF COWS RAISING CALVES.[1]

By E. W. Sheets and R. H. Tuckwiller, *Animal Husbandry Division.*[2]

I. RATIONS, GAINS AND LOSSES IN WEIGHT, AND CALVES PRODUCED.

II. COSTS OF THE RATIONS AND OF RAISING CALVES TO WEANING AGE.

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OUTLINE OF THE EXPERIMENTAL WORK.

LOCATION OF THE EXPERIMENT.

The work reported in this bulletin is part of a series of beef-cattle experiments that have been in progress since December 22, 1914. They have been carried on cooperatively by the Bureau of Animal Industry of the United States Department of Agriculture and the West Virginia Agricultural Experiment Station, on the farm of

[1] A report of cooperative work by the Bureau of Animal Industry, United States Department of Agriculture, and the West Virginia Agricultural Experiment Station.

[2] The authors acknowledge the services of W. F. Ward and F. W. Farley, formerly of the Animal Husbandry Division, who assisted in planning and carrying on the work.

David Tuckwiller, in Greenbrier County, W. Va., to study beef-production problems in the Appalachian Mountain region. This farm is located in the southeastern part of the State in the bluegrass area. The results of this experiment apply not only to West Virginia, but also to the adjacent States having similar conditions, as shown in the outline map (fig. 1). Some of the methods are so generally applicable that the results may be utilized to advantage by cattle raisers in other parts of the country.

THE REGION AND ITS PROBLEMS.

The topography in most parts of the region, except in the vicinity of streams, is gently rolling or even mountainous in the higher elevations. The area is generally cleared of forest trees, although vast areas of cut-over or stump land are found. The farms vary in size from less than 100 acres to more than 1,000 acres. The land is especially well adapted for grazing, and in most sections there is tillable land for the production of abundant crops for winter feed or other purposes.

Fig. 1.—Region to which this work applies. The black dot indicates the location of the farm on which the experiment was conducted. The shaded portion represents the area to which the results are applicable, and the dotted portion shows an additional area to which the results apply in part.

In this general area are produced a large percentage of the grass-finished cattle which go annually to eastern markets. The fact that most of the steers produced in this area are finished for market on grass alone attests the value of the pastures, which consist largely of bluegrass. The use of grain for finishing cattle is not general, although the practice is followed in some sections, particularly in the valleys of the larger streams.

As a rule most grazers and feeders of beef steers do not raise calves to supply their needs for stockers. One of their chief problems, therefore, is to obtain calves, yearling steers, or 2-year-old steers of suitable beef type to use their feed to the best advantage. Many farmers keep only a small number of cows to produce milk and butter for their families. Some of them keep good beef cows, breed them to good bulls, and raise good calves by giving them a large part of the cows' milk. Others keep cows of the dairy type or of mixed dairy breeding, and breed them to either nondescript or dairy bulls. Calves

from such breeding, as a rule, make undesirable stockers. When they are poorly fed, as is often the case, they are even more undesirable. When good purebred beef bulls are used on such cows, fairly good stocker calves can be raised. The best calves, however, are produced by the use of good beef cows, bred to good purebred beef bulls. There is a ready market for the latter type of calves among those who graze and feed stockers or older cattle.

Since the tendency of many small farmers seems to be to keep only a few cows that produce large quantities of milk, the cattle grazers and feeders in this area may be forced to raise their own calves as the business of feeding cattle grows and the demand for a better class of cattle increases. The questions then arise, what does it cost to keep a cow of good beef type solely for the calf she may raise, and how may she be fed most economically?

OBJECTS AND PLAN OF THE WORK.

The experimental work reported in this bulletin was undertaken with the following objects:

1. To determine the most satisfactory and economical method of wintering beef cows to raise calves.
2. To find the cost of raising the calves.

The work was carried on for a period of four years, in order to have an average of feeds, cattle, seasons, and other conditions tending to produce variation. The general plan of the experiment is given in Table 1.

TABLE 1.—*Plan of the four years' work.*

Lot No.	Season.	Cows in lot.	Winter feed.	Summer feed.
1	1915–16	10	Corn silage, mixed hay, and wheat straw	Pasture.
	1916–17	10	do	Do.
	1917–18	10	do	Do.
	1918–19	10	do	Do.
2	1916–17	10	Corn silage, soy bean hay, and wheat straw	Do.
	1917–18	10	do	Do.
	1918–19	10	do	Do.
3	1915–16	10	Corn silage, cottonseed meal, and wheat straw	Do.
	1916–17	10	do	Do.
	1917–18	10	do	Do.
	1918–19	10	do	Do.
[1] 4	1915–16	10	Shock corn, mixed hay, and wheat straw	Do.

[1] Originally it was planned to feed shock corn, mixed hay, and wheat straw to Lot 4 throughout the experiment, but because the ration was so much more expensive than the silage rations and because it did not maintain the cows so well as the silage rations it was abandoned after the first year.

DESCRIPTION OF COWS.

The cows used were grades of the Shorthorn, Hereford, and Aberdeen-Angus breeds. (See figs. 3, 4, and 5.) In the fall of the first

year the cows, which were bred to calve in the spring or early summer, were bought in the surrounding section. While most of the cows had been bred to purebred bulls, a few had been bred to high-grade bulls. During the following years as many as possible of

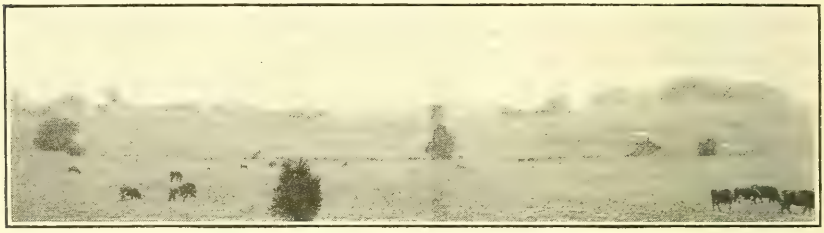

FIG. 2.—Character of the land and pasture.

these cows were bred during the summer to a purebred bull. As some of them failed to get with calf early enough to provide a uniform lot of calves, other cows and heifers were used to replace them.

FEEDS USED.

Samples of the feeds were taken at different times during the winter periods and sent to the Department of Chemistry, West Virginia Agricultural Experiment Station, Morgantown, W. Va., to be ana-

FIG. 3.—Lot 1. Cows fed corn silage, mixed hay, and wheat straw, at the end of the winter period, Apr. 25, 1919.

lyzed. The averages of these analyses are shown in Table 2, in heavy type, while the average analyses for several thousand samples, as computed by the United States Department of Agriculture, are shown in ordinary type.

TABLE 2.—*Composition of feeds used.*

Feed.	Moisture.	Ash.	Protein.	Carbohydrates, including fiber.	Fat
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Corn silage	**75.0**	**1.1**	**1.9**	**21.5**	**0.5**
	70.9	1.4	2.4	24.4	0.9
Mixed hay	**8.3**	**3.7**	**6.6**	**79.5**	**1.9**
Wheat straw	**8.4**	**3.2**	**2.9**	**84.1**	**1.4**
	9.6	4.2	3.4	81.5	1.3
Soy-bean hay	**9.0**	**9.1**	**10.0**	**68.9**	**3.0**
	8.4	8.9	15.8	63.1	3.8
Cottonseed meal	**7.8**	**6.0**	**37.6**	**40.3**	**8.3**
	7.3	5.8	36.8	43.5	6.6
Shock corn	11.8	5.8	7.4	72.6	2.4

From the analyses it is evident that the feeds used, with the exception of cottonseed meal, were somewhat below the average in quality. The cottonseed meal used was a little better than the average cottonseed meal graded as "good" by the Association of Feed Control Officials of the United States.

FIG. 4.—Cows fed corn silage, soy-bean hay, and wheat straw, at the end of the winter period, Apr. 25, 1919.

FEED CROPS IN THE REGION.

A 3-year rotation of crops, consisting of corn, wheat, and hay, is practiced rather generally in the region under discussion. Timothy is sown with the wheat in the fall, and red clover is sown on the same field in the spring. This provides in the year following the

wheat crop a mixed hay of approximately one-half timothy and one-half clover. In making soy-bean hay the ground is prepared about as it would be for corn. The beans are drilled broadcast, using 1½ bushels an acre. They are usually sown the last of May or the first of June, after all danger of heavy frost is past. When the beans begin to form in the pods, about the first of September, the time varying with the variety of beans and the kind of season, the crop is cut and cured for hay.

KIND OF PASTURE.

Each year the cows and their calves were turned on a pasture of about 120 acres.

The soil is of limestone formation and a good growth of bluegrass with much white clover is found on all parts of the pasture, which is typical of this section. Under normal climatic conditions there is rainfall enough to keep the grass growing throughout the season.

METHOD OF FEEDING AND HANDLING.

In the fall, before being started on the winter feed, the cows were divided into lots of 10 each. In this division care was taken to have the lots as uniform as possible in quality, breeding, size, and condition. These different lots were allowed the same amount of space in open sheds with small outside lots about 25 by 50 feet in size. Water was supplied in these lots at all times and salt was constantly available. The cows were fed twice a day.

The feed, both concentrates and roughages, was weighed at each feeding and accurate records kept of the quantities fed. The cows were weighed individually at the beginning, and at the end of the winter feeding period, the weights being taken 3 days in succession and the averages taken as their initial and final weights. They were also weighed once every 28 days. The weights were taken in the morning after feeding. For identification, neck straps with numbers on them were used.

After the cows were turned on grass in the spring it was necessary in some instances where the cows gave a heavy flow of milk to give the calves only a part of the milk until they were old enough to take it all.

I. RATIONS, GAINS AND LOSSES IN WEIGHT, AND CALVES PRODUCED.

FEED CONSUMED.

These cows received only enough feed to keep them in good, strong, thrifty condition. As the graph in figure 7 shows, they gained in weight until they calved.

Table 3 shows the total amount of feeds consumed by the various lots and the average ration per cow in each lot for the four winters.

TABLE 3.—*Average total and daily rations during four winters.*

Lot and ration.	Total feed per cow.					Daily feed per cow.				
	1915–16 (122 days).	1916–17 (137 days).	1917–18 (135 days).	1918–19 (134 days).	Average.	1915–16 (122 days).	1916–17 (137 days).	1917–18 (135 days).	1918–19 (134 days).	Average.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
Lot 1:										
Corn silage	2,440	3,398	2,889	3,480	3,052	20	24.8	21.4	26.0	23.1
Mixed hay	976	1,096	977	1,094	1,036	8	8	7.2	8.2	7.8
Wheat straw	334	367	338	355	348	2.7	2.7	2.5	2.6	2.6
Lot 2:										
Corn silage	.....	3,398	2,289	3,480	3,256	.....	24.8	21.4	26.0	24.1
Soy-bean hay	.....	1,096	945	960	1.000	.....	8	7	7.2	7.4
Wheat straw	.....	225	324	355	301	.....	1.6	2.4	2.6	2.2
Lot 3:										
Corn silage	3,050	3,398	2,889	3,480	3,204	25	24.8	21.4	26.0	24.3
Cottonseed meal	183	205.5	202.5	201	198	1.5	1.5	1.5	1.5	1.5
Wheat straw	976	995	864	960	949	8	7 3	6.4	7.2	7.2
Lot 4:										
Shock corn	1,830	.....	.....	.....	.....	15	.....	.....	.....	.....
Mixed hay	1,220	.....	.....	.....	.....	10	.....	.....	.....	.....
Wheat straw	224	.....	.....	.....	.....	1.8	.....	.....	.....	.....

The composition and the nutritive ratio of the rations fed are given in Table 4.

TABLE 4.—*Quantities of dry matter and digestible nutrients in the feeds, and nutritive ratios of the rations.*

Lot No.	Ration.	Daily feed per cow.	Dry matter.	Digestible nutrients.		Nutritive ratio.
				Protein.	Carbohydrate equivalent.[1]	
		Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
1	Corn silage	23.1	5.77	0.32	4.37	
	Mixed hay	7.8	7.15	.45	3.43	
	Wheat straw	2.6	2.35	.10	.97	1:10.1
		.....	15.27	.87	8.77	
2	Corn silage	24.1	6.02	.34	4.55	
	Soy-bean hay	7.4	6.73	.83	3.26	
	Wheat straw	2.2	1.99	.01	.82	1: 7.3
		.....	14.74	1.18	8.63	
3	Corn silage	24.3	6.07	.34	4.59	
	Cottonseed meal	1.5	1.38	.46	.63	
	Wheat straw	7.2	6.51	.03	2.67	1: 9.5
		.....	13.96	.83	7.89	
4	Shock corn	15.0	13.23	.61	8.34	
	Mixed hay	10.0	9.17	.58	4.39	
	Wheat straw	1.8	1.63	.01	.67	1:11.2
		.....	24.03	1.20	13.40	

[1] The carbohydrate equivalent is the sum of the digestible carbohydrates plus 2.25 times the digestible fat.

CALVES PRODUCED AND THEIR BIRTH WEIGHTS.

The following table shows the number of calves born and raised in each lot each season, with the average weight at birth of each lot.

TABLE 5.—*Numbers and birth weights of calves produced by each lot of cows.*

Lot No.	Ration.	Season.	Calves born per lot.	Calves raised per lot.	Average birth weight per calf, by lots.
					Pounds.
1	Corn silage, mixed hay, and straw	1915–16	10	10	62.9
		1917–18	9	9	70.3
		1918–19	10	10	64.6
	Average		9.7	9.7	65.8
2	Corn silage, soy-bean hay, straw	1917–18	10	10	62.8
		1918–19	9	9	73.0
	Average		9.5	9.5	67.6
3	Corn silage, straw, and cottonseed meal	1915–16	10	9	67.0
		1917–18	8	7	64.6
		1918–19	10	10	64.6
	Average		9.3	8.7	65.5
4	Shock corn, mixed hay, and straw	1915–16	10	9	61.1

Table 5 shows that, in 1915–16, 30 calves were dropped, 2 of which died. In 1916–17 the cows were sold at the end of the winter feeding

FIG. 5.—Lot 3. Cows fed corn silage, cottonseed meal, and wheat straw, at the end of the winter period, Apr. 25, 1919.

period. In 1917–18, 27 calves were dropped. 1 of which died. In 1918–19, 29 of the cows dropped calves and raised all of them.

Most of the calves were dropped in April and May and a few in March and June, one half of them being dropped before the cows were turned to pasture and the other half after. The average date on which the calves were dropped was April 20. The average per cent of calves raised by the three lots of 10 cows each for three years was 92. Such numbers of calves can not be produced from 30 cows year after year if the same cows are kept. In these tests if the cows did not become settled in calf so as to drop calves at the desired time others were substituted.

While the average birth weight of the calves of Lot 2, which, according to Table 3, was fed considerably more digestible protein than Lots 1 and 3, is 2 pounds more, this may not be significant, because it averaged less than the birth weights of the other lots in 1917–18.

The smallest average birth weight, that of the calves of Lot 4, may be due to the lack of succulence in the ration, yet the difference does not seem significant, as it is small and represents only one year's work.

GAINS AND LOSSES IN WEIGHT.

Table 6 shows the gains or losses of each lot during the winter periods.

TABLE 6.—*Results during four winters.*

Lot No.	Ration.	Season.	Days fed.	Average initial weight per cow.	Average final weight per cow.	Average gain (+) or loss (−) per cow.	Calves dropped before turning on pasture.	Average age of calves at end of winter.
			Days.	*Pounds.*	*Pounds.*	*Pounds.*	*Number.*	*Days.*
1	Corn silage, mixed hay, and wheat straw.	1915–16	122	865	779	−87	6	30
		1916–17	137	855	879	+24	.....	.....
		1917–18	134	740	766	+26	1	15
		1918–19	134	858	879	+21	5	38
	Average	.....	132	830	826	−4	.....	.....
2	Corn silage, soy-bean hay, and wheat straw.	1916–17	137	829	870	+41	.....	.....
		1917–18	134	740	789	+49	3	4
		1918–19	134	857	909	+52	6	28
	Average	.....	135	809	856	+47	.....	.....
3	Corn silage, cottonseed meal, and wheat straw.	1915–16	122	870	835	−35	8	23
		1916–17	137	849	873	+24	.....	.....
		1917–18	134	733	808	+75	3	6
		1918–19	134	857	873	+16	6	33
	Average	.....	132	827	847	+20	.....	.....
4	Shock corn, mixed hay, and wheat straw.	1915–16	122	867	818	−49	5	27

The main fact shown in this table is that all the different lots of cows, except in 1915–16, gained from 20 to 75 pounds from the beginning of the feeding period in December until they were turned on pasture. In 1915–16 the silage-fed lots lost weight because the

silage was of poor quality, part of it being made from silage corn, and because they got less feed in proportion to their weight. As Lot 4, fed shock corn, according to Table 3 received more protein and considerably more carbohydrates than Lots 1 and 3, their loss in weight is attributed to the lack of succulence in their ration. The average date on which the cows were turned to pasture was April 22, two days later than the average date on which the calves were dropped.

The last two columns of Table 6 give the number of calves dropped in each lot during the winter period and their average age at the end of that time.

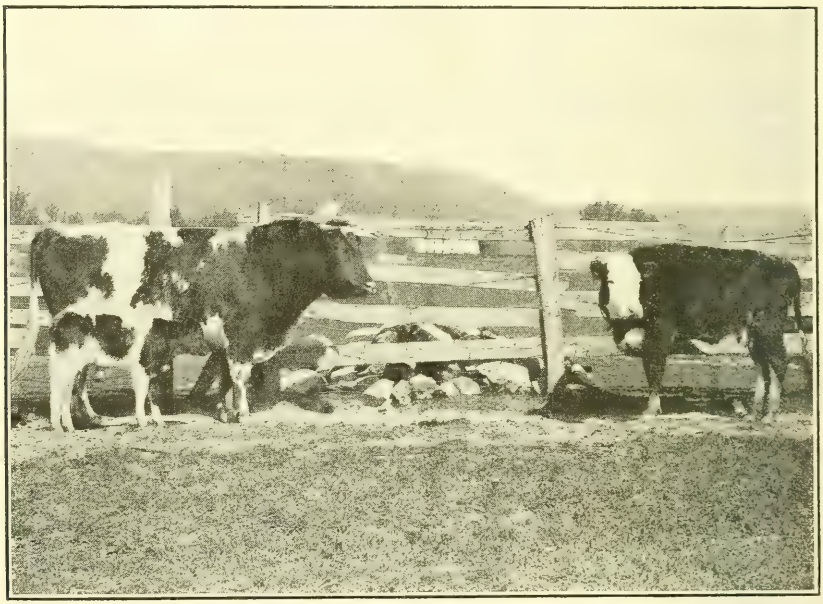

FIG. 6.—Sire, dam, and offspring. The sire is the registered Shorthorn bull to which the cows, used in this experiment, were bred. Note the prepotency of the purebred sire as indicated by the calf.

The relative gain or loss of the cows during the winter and until all the cows had dropped calves does not signify much, because on any weigh day there was usually a different number of cows that had dropped calves in the different lots. During each year some of the cows calved during the latter part of the winter feeding period and the others after they were turned on grass. A cow just after dropping her calf and for some time afterwards continues to lose weight, especially if milking heavily. Lot 3, receiving silage, straw, and cottonseed meal, seemed to stay in the best condition through the winter.

Table 7 shows the gains or losses per cow made during summer and winter periods and net gain for the year period.

TABLE 7.—*Gains and losses during two summers on pasture and total gains for winter and summer.*

Lot No.	Season.	Number of cows.	Days on pasture.	Weights on pasture.		Gain (+) or loss (−) per cow.		
				Initial.	Final.	Summer.	Winter.	Winter and summer.
				Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
1	1915–16	10	140	779	916	+137	−86	+51
	1917–18	10	140	766	761	−5	+26	+21
	Average			772	838	+66	−30	+36
2	1917–18	10	140	789	789		+49	+49
3	1915–16	10	140	835	916	+81	−35	+46
	1917–18	10	140	808	803	−5	+75	+70
	Average			821	859	+38	+20	+58
4	1915–16	10	140	818	877	+59	−49	+10

The chief value of Table 7 is that it shows what gains may be made by cows on grass while they are suckling calves. It also shows that the lots which lost in weight during the winter made greater gains during the following summer than the lots which had maintained their weight through the winter. However, the lots which had maintained their weight through the winter made greater gains for the whole year than the lots which had lost in weight during the winter.

GRAPHIC PRESENTATION OF MONTHLY WEIGHTS.

The gains and losses in weight from month to month made by each lot of cows during 1915–16 and 1917–18 are shown graphically in figure 7.

The horizontal distance on the chart indicates the number of days the cows were fed during the winters and pastured during the summers. The average length of the total period for the 2 years was 324 days, of which 128 days were in the winter period and 196 in the summer period. The heavy black vertical line near the center of the chart marks the dividing line between the winter and summer periods. Vertical distance represents changes in live weight of the cows as indicated by the figures along the left side of the chart. The curves for the cows of Lots 1 and 3 represent an average of 2 years' feeding, while those for Lots 2 and 4 represent only 1 year's feeding. Figure 8, showing the gains made by the calves is based on the feeding year 1915–16 alone, because no complete records were obtained for 1916–17, 1917–18, and 1918–19, the calves having been sold before the end of the summer periods.

Since the average weight of the cows for 1915–16 and 1917–18 was 799 pounds, all the lots are started at the 800-pound line to

make them more readily comparable. The time of beginning the winter period and the length of it are also averaged, to have the graphs on a uniform basis. The winter period in 1915–16 began December 22 and lasted 122 days, while the winter period in 1917–18 began December 7 and lasted 134 days. This makes the average time of beginning the winter period December 14, and the average length of the last section of the winter period 16 days.

In studying the variations in the weights of the cows from month to month, it should be kept in mind that the average time of calving for the 2 years represented in figure 7 was practically the same as the time when cows were turned on to pasture.

The average birth date of the 19 calves of lot 1 during 1915–16 and 1917–18 was 2 days after the cows were turned on pasture; for

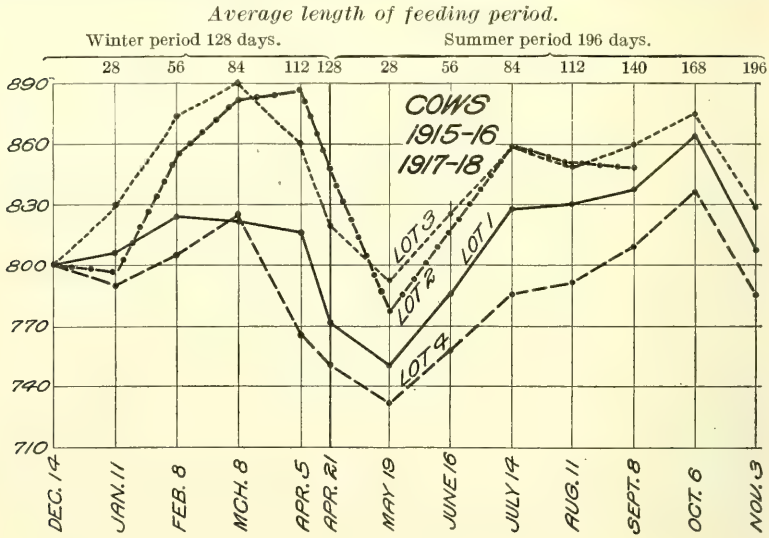

Fig. 7.—Gains and losses in weight of cows.

the 10 calves of lot 2 in 1917–18, 7 days before; for the 16 calves of lot 3 in 1915–16 and 1917–18, 6 days after; and for the 10 calves of lot 4 in 1915–16, 1.5 days after.

Figure 8 shows how the calves gained in weight during 1915–16. The average weight of the calves for each weight day, designated by the vertical lines, was obtained by dividing the total weight of the calves in each lot by the number of cows in each lot. It should be kept in mind here that most of the calves were dropped in April and in May and that about one-half were dropped before and the other half after the cows were turned on pasture.

Figure 7 shows that the cows gained in weight during the winter period until they began to drop calves. This is generally expected in wintering beef cows. The cows lost in weight during the rest of the winter and continued to lose weight during the first 28 days

on pasture. During the following 56 days they gained in weight rapidly, following which for the next 56 days they about maintained their weight. Then, when it was cooler and they began to dry up, they gained in weight, but lost heavily in October, when rains and frost usually lower the feeding value of pasture considerably.

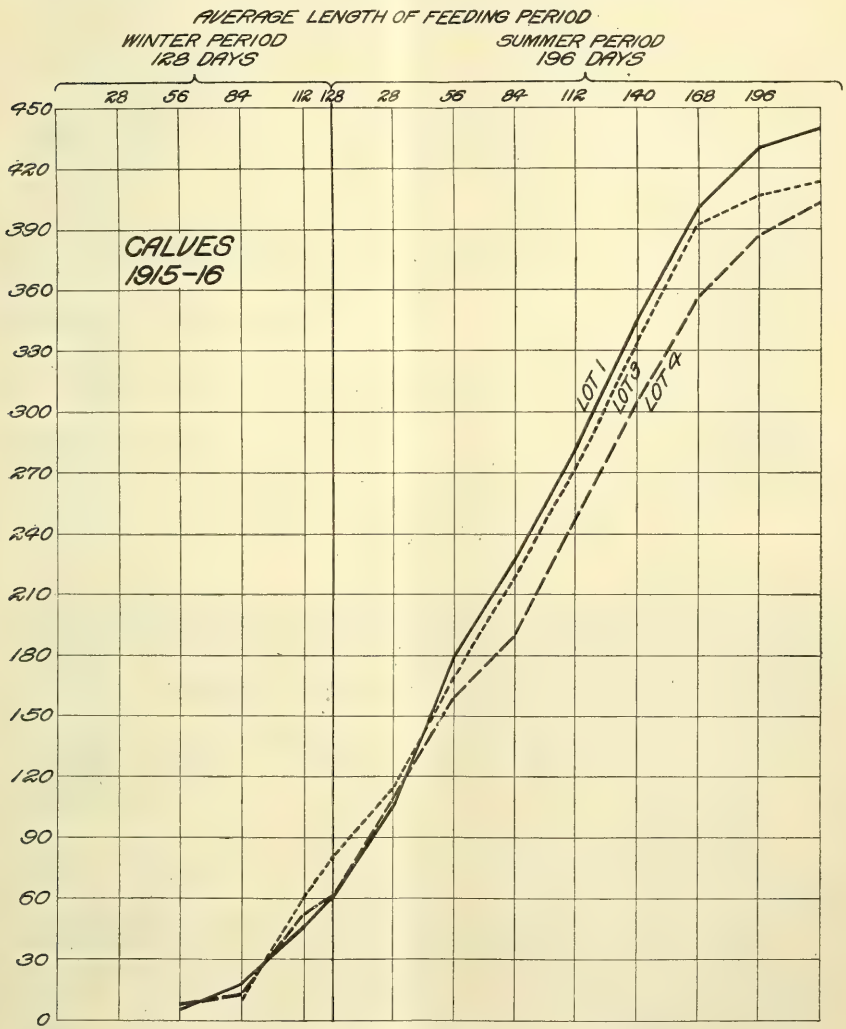

FIG. 8.—Gains of calves, season of 1915–16.

The calves gained in weight very uniformly until October, when the smaller amount of milk given by the cows and the poorer pasture, caused the rate of gain to be somewhat less.

FEEDS CONSUMED PER 1,000 POUNDS LIVE WEIGHT AND PER CALF RAISED.

Table 8 is for the convenience of those who may have larger or smaller cows than were used in this project and who may want to

calculate how much feed will be required to winter the herd. In case the feeding period is longer or shorter than the one in this experiment, the column showing the daily feed consumed per 1,000 pounds live weight may be used to advantage.

TABLE 8.—*Summary of feed consumed per 1,000 pounds live weight of cow, and per calf raised to weaning age.*

Lot No.	Ration.	Feed per 1,000 pounds live weight of cow.		Feed per calf raised.
		Total.	Daily.	
		Pounds.	*Pounds.*	*Pounds.*
1	Corn silage	3,688	27.9	3,038
	Mixed hay	1,252	9.5	1,051
	Wheat straw	421	3.2	354
2	Corn silage	3,911	28.9	3,352
	Soy-bean hay	1,201	8.9	1,003
	Wheat straw	362	2.7	357
3	Corn silage	3,830	29.0	3,623
	Wheat straw	1,134	8.6	1,077
	Cottonseed meal	237	1.8	226
4	Shock corn	2,172	17.8	2,033
	Mixed hay	1,448	11.9	1,356
	Wheat straw	266	2.2	249

SUMMARY OF FEEDING AND HANDLING.

1. For carrying an 834-pound grade beef cow that is to drop a calf in the spring or early summer through an average winter period of 132 days, the following quantities of feed per day were required to make the corresponding gains or losses in weight during the winter:

		Feed consumed	Gain (+) or loss (—) in weight.
		Pounds.	Pounds.
Lot 1.	Corn silage	23.1	— 4
	Mixed hay	7.8	
	Wheat straw	2.6	
Lot 2.	Corn silage	24.1	+47
	Soy-bean hay	7.4	
	Wheat straw	2.2	
Lot 3.	Corn silage	24.3	+20
	Cottonseed meal	1.5	
	Wheat straw	7.2	
Lot 4.	Shock corn	15.0	—49
	Mixed hay	10.0	
	Wheat straw	1.8	

2. The average birth weight of the calves and the gains in weight made during both winter and summer periods indicate that the above-mentioned rations should be ranked 2, 3, 1, and 4.

3. Unless cows which do not settle within 3 or 4 months after calving are replaced by bred cows or heifers, the breeder loses for the following reasons:

A smaller calf crop each year.
A lack of uniformity in the ages of the calves.
A greater labor, feed, and equipment cost if the calves are dropped in the fall or winter.
Greater inconvenience and cost in handling when all the calves do not come in one season.

It seems advisable for farmers raising grade beef calves to use as many 2-year-old heifers as they can produce or purchase at a reasonable cost. Heifers raise good calves and at the same time make a considerable gain in weight if they are fed properly. When the calves are weaned the heifers can be fattened, sold, and replaced by more 2-year-olds. This gain in weight by growth can not be obtained in the case of aged cows.

II. COSTS OF THE RATIONS AND OF RAISING CALVES TO WEANING AGE.

The following comparisons are made to see which is the cheapest of the various rations used in the experiment, and especially to see with which one the calves were produced most cheaply.

PRICES USED.

For the purpose mentioned it is necessary to fix the prices for feeds on the farm. This is the most questionable and unsatisfactory part of such experimental work, especially for the last few years, during which unusual fluctuations have occurred in feed prices. On account of these fluctuations and also for simplicity in making the various calculations, an average of the feed prices for the three years is used, as follows:

Corn silage	per ton	$6.00
Mixed hay	do	18.00
Soy-bean hay	do	17.00
Cottonseed meal	do	50.00
Wheat straw	do	7.00
Corn stover	do	7.00
Shock corn	do	17.00
Ear corn	per bushel	.96
Pasture	per day	.06

The foregoing figures are based on the average farm prices of corn and hay from 1910 to 1919, as given in the Yearbook of the United States Department of Agriculture, for the States of West Virginia, Virginia, Maryland, Pennsylvania, Ohio, Kentucky, Tennessee, and North Carolina.

To determine which ration should be used in a particular feeding operation, it is suggested that the feeder apply local prices to the average amounts of the feeds consumed per cow, as given in Tables 3 and 8.

COSTS OF RATIONS AND OF CALVES PRODUCED.

Because of the unusually high percentage of calves dropped, which was due to the practice of substituting cows that were bred for any which failed to breed in time for a spring calf the following year, the cost per cow kept is only slightly less than the cost per calf raised, as Table 9 shows. It is considered that the cost of labor, the bull charges, and other expenses are balanced by the manure produced.

TABLE 9.—*Cost of feeding the cows during the four years and the average cost for each calf raised to weaning age.*

Lot No.	Ration.	Season.	Cost to winter per cow.	Total cost per year per cow.[1]	Cost per calf raised
1	Corn silage, mixed hay, and wheat straw	1915–16	$17.27	$31.91	$31.91
		1916–17	21.33	35.01	.....
		1917–18	18.64	32.44	36.04
		1918–19	21.53	35.39	35.39
	Average	.....	19.69	33.69	34.39
2	Corn silage, soy-bean hay, and wheat straw	1916–17	20.30	33.98	.....
		1917–18	17.83	31.63	31.63
		1918–19	19.84	33.70	37.44
	Average	.....	19.32	33.10	34.38
3	Corn silage, cottonseed meal, and wheat straw	1915–16	17.13	31.77	35.30
		1916–17	18.81	32.49	.....
		1917–18	16.75	30.55	43.57
		1918–19	18.83	32.69	32.69
	Average	.....	17.88	31.87	36.54
4	Shock corn, mixed hay, and wheat straw	1915–16	27.50	42.14	46.82

[1] The cost of keeping a cow a year in this table is for 365 days, instead of for the winter period of 132 days and 140 days in summer while suckling calves, as reported in Tables 6 and 7.

COMPARISON OF RESULTS WITH SILAGE AND SHOCK CORN.

TABLE 10.—*Comparative value of the silage rations and the shock-corn ration.*

Item.	Lot 1. Corn silage, mixed hay, wheat straw.	Lot 2. Corn silage, soy-bean hay, wheat straw.	Lot 3. Corn silage, cottonseed meal, wheat straw.	Lot 4. Shock corn, wheat straw.
Average yearly gain per cow ..... pounds	36	49	61	10
Winter gains and losses per cow ..... do	−4	+47	+20	−49
Percentage of calves raised per year ..... per cent	97	95	87	90
Average birth weight of calf ..... pounds	65.9	67.9	65.4	61.1
Cost per cow to winter	$19.69	$19.32	$17.88	$27.50
Cost per cow per day to winter	.15	.14	.14	.22½
Total cost of feed per cow for one year	33.69	33.10	31.87	42.14
Daily cost of feed per cow for one year	.09	.09	.09	.11½
Cost of feed per calf raised	34.39	34.38	36.54	46.82
Saving per cow by using silage	8.45	9.04	10.27	.....
Saving per calf raised	12.43	12.44	10.28	.....

SUMMARY OF COSTS.

1. Corn silage and wheat straw with either mixed hay, soy-bean hay, or cottonseed meal is a much cheaper ration than shock corn, mixed hay, and wheat straw for wintering grade beef cows.

2. As the cows fed on the mixed hay and soy-bean ration produced a larger calf crop than those fed the cottonseed meal, the average cost per head of raising their calves was practically 6 per cent less.

3. As sources of protein, mixed hay, and soy-bean hay, where they are grown successfully, have additional advantages in that they can be raised on the farm, while cottonseed meal must be purchased, which involves uncertainty as to the availability and the price.

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WM. A. TAYLOR, Chief

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STUDIES IN THE CLARIFICATION OF UNFERMENTED FRUIT JUICES.

By JOSEPH S. CALDWELL, *Plant Physiologist, Office of Horticultural and Pomological Investigations.*

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PURPOSE AND SCOPE OF THE INVESTIGATION.

When an unfermented fruit juice, such as that of apples or grapes, is prepared and preserved by the methods ordinarily employed, a more or less copious precipitate consisting of cellular débris and heat-coagulable material is formed after pasteurization. This fact is responsible for the usual practice of pasteurization and storage, followed after an interval by transfer to the final containers and a second pasteurization. Even when the formation of a coagulum in the final container is thus prevented, the liquid remains permanently turbid and opaque from the presence of considerable quantities of suspended colloidal materials, which are unaffected by heating and subsequent storage. In the case of a few heavily pigmented varieties of grapes, such as the Ives, Concord, Clevener, and other purple varieties, the intense coloration of the juices masks their turbidity and renders them attractive to the eye. In most grape varieties, however, the juices obtained are densely opaque, tawny yellow, or

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brownish colloidal suspensions, distinctly uninviting in appearance. While a considerable number of these juices are superior in flavor and in beverage quality to juices of the Concord type, their appearance counts so heavily against them that, with the exception of Catawba, no systematic attempts have been made to place them on the market, and they seem to be very little used for juice making even in districts in which the production of such varieties is in excess of market demands for fresh grapes.

Unfermented apple juice, or "sweet cider," is to a very large extent a seasonal product, made and consumed in large quantities during the autumn months, but practically unobtainable at other seasons. Pasteurized unfermented cider has not gained greatly in popularity, its consumption in recent years having entirely failed to keep pace with the increase in consumption of synthetic soft drinks. While this failure to gain in favor has been due in considerable part to lack of uniformity in the character and quality of the product and to loss of distinctive flavor or development of foreign flavors as a result of faulty preparation, the criticism most frequently heard is that pasteurized ciders are "muddy" and unattractive looking on account of the presence of suspended matter. In view of the reception given the clear, attractive juices placed on the market by a few manufacturers employing zealously guarded special methods of preparation, it seems certain that a very considerable increase in demand and consumption as well as a very large extension of the small-scale home manufacture of unfermented juices would result if simple, effective methods of making brilliant, transparent juices of unaltered beverage quality were generally available.

One of the purposes of the studies of fruit juices which have been in progress in the Bureau of Plant Industry for the last three years is the development of simple, generally available methods for the preparation of unfermented fruit-juice beverages, by which the fruit grower or the individual consumer may make products of good quality, distinctive flavor, and attractive appearance without the use of special equipment. Concurrently a large number of varieties of apples and grapes have been studied with reference to their special fitness for the making of various products. It has consequently been possible to employ in the work each year samples of juices from approximately 250 varieties of apples and more than 60 varieties of grapes, including nearly all the more widely distributed varieties of these fruits. Materials of the greatest possible diversity have been available for study, affording an unusual opportunity for testing the general applicability of proposed methods.

At the outset the devising of satisfactory methods of clarification was recognized as a very important part of the problem, requiring entrance into a very imperfectly known portion of the field of colloid

chemistry. It is known that the specific flavor of a fruit juice is determined in part by the ratio borne by one of the colloids (tannin) to the acid and sugar content and in part by very imperfectly known and complex constituents which are probably in the colloidal condition. While many of the pigments which give juices their color are crystalline substances, others are either colloids or closely associated with colloids. In order that a juice may be clarified without reducing its value as a beverage, these constituents must remain unaltered by the treatment, which must at the same time completely remove from the liquid other colloids, including pectins, gums, complex carbohydrates, and nitrogenous bodies. The methods which may be employed to make such a separation are greatly restricted by the conditions, and the preservation of desirable constituents is more difficult than the removal of the undesirable ones. This is especially the case in devising methods which the small producer without special equipment can use.

For these reasons, the literature dealing, both from the theoretical and from the practical point of view, with the clarification of such colloidal solutions as are encountered in brewing, wine making, and sugar manufacture was examined for suggestions as to possible lines of attack, and considerable time was spent in determining the applicability to the problem in hand of methods used in these industries. No attempt to review this enormous literature will be made, but it may be of interest to state the unsatisfactory or negative results obtained in attempts to utilize some of these methods before describing the method found most effective.

METHODS OF CLARIFICATION GENERALLY EMPLOYED.

The methods of clarification employed by wine makers and brewers and in sugar manufacture may be grouped broadly into three classes: (1) Those in which the colloid is destroyed by the use of enzyms; (2) those which bring about by chemical treatment the formation of a precipitate which "envelops" and carries down suspended material; and (3) those in which the colloid is removed by adsorption upon insoluble, chemically inert adsorbing agents.

CLARIFICATION BY MEANS OF ENZYMS.

The Wallerstein (*10*, *27*, *28*, *29*)[1] process for the prevention of the development of cloudiness, or "haze," in bottled beer when placed upon ice prior to serving is an instance of the first treatment. According to the results of Brown's extended investigations (*4*), the appearance of "haze" under such conditions is due to the presence in

[1] Serial numbers (italic) in parentheses refer to "Literature cited" at the end of this bulletin.

the finished beer of a reversible colloid formed by combination of hop tannin with a protein of the wort. The solubility of this colloid is decreased by cooling the liquid, with the result that turbidity appears at low temperatures but disappears again on warming. In the Wallerstein process (*10*, p. 605–607; *27*, *28*, *29*) a proteolytic enzym, which can be either pepsin, papain, or bromelin, is added to the beer at the end of the main fermentation in amounts of 1 to 2 grams per hundred liters. The protein-tannin compound is attacked and converted into simpler completely soluble products by the enzym, with the result that the beer remains clear irrespective of the temperatures to which it may later be subjected.

Because of the number and diverse character of the constituents which it is desirable to remove, as well as the character of those which must be preserved, it appeared inherently improbable that enzyms could be successfully employed in the clarification of apple or grape juice or that, even if such a process could be developed, it could be made of such character as to be generally usable. Inasmuch as no indication could be found in the literature that any investigation into the possibilities had been made, some work was begun in 1918. It is still in progress and will be reported elsewhere. It has been possible under laboratory conditions to obtain satisfactory clarification combined with the preservation of the characteristic flavors of juices by the use of enzyms, but the method has not as yet been sufficiently simplified to meet the need for a method requiring no special technical skill and usable on any scale.

French cider makers lay much stress upon the coagulation of the pectins of apple must immediately after pressing as an essential step in the making of high-grade clear ciders. Warcollier (*30*) recommends that juices be held at 4° or 5° C. until the pectase present has coagulated the pectins which collect at the surface to form the "chapeau," or "head," and the settlement of cellular débris and dirt to the bottom has occurred. He suggests that elimination of most of the undesirable organisms which might injuriously affect the subsequent fermentation will thereby be effected. He states that the juice will be perfectly limpid and clear if the conditions be made such that fermentation be prevented during the period of defecation. Arnou (*3*, p. 80–84) devotes a considerable section of his work to the subject, stating that the permissible range of temperature is from 6° to 12° C. and the time required from 12 to 24 hours. In case the juice is deficient in pectase, Arnou suggests the use of sodium or potassium carbonate, calcium sulphate, potassium metabisulphite, or sodium chlorid, and quotes Warcollier as advocating the use of 80 grams of tartaric acid and 30 grams of calcium carbonate per hectoliter of juice to hasten coagulation. He also remarks that apples from differ-

ent districts of France (hence presumably of different varieties) show differences in the readiness with which coagulation of the pectins is obtained, that neither green nor overripe fruits give satisfactory results, that juices low in acid and tannin content coagulate readily, and that successful coagulation is obtained only when fermentation is prevented during the period of defecation.

It has been impossible in the laboratory of the Bureau of Plant Industry to produce such results as are described by these authors without having recourse to some of the chemical treatments which they suggest. At a temperature of 4° C. pectase is inactivated or acts so slowly as to fail entirely to bring about coagulation of the pectins. At higher temperatures alcoholic fermentation is not prevented and usually proceeds so rapidly as soon to make it impossible to classify the juice as unfermented. It is possible to produce almost instantaneous coagulation of pectins by some of the chemical treatments outlined by the French writers cited, but such treatments are not to be recommended, for the reason that their employment seriously detracts from the beverage quality of the juice.

CLARIFICATION BY THE FORMATION OF A PRECIPITATE.

Various methods of clarification employed in wine making and vinegar making may be grouped together, since they all depend upon the production in the liquid of a voluminous precipitate, which gradually subsides, carrying down with it the particles causing turbidity. A rather careful study of such methods indicates that none of them can be expected to give satisfactory results with unfermented juices. The method of clarifying wines most widely employed by European wine makers and most fully discussed in works on wine making is precipitation by the addition of tannin and gelatin. Since the precipitate is the product of a definite chemical reaction, perfect results are obtainable only when the quantities of the reagents are exactly adjusted, a slight excess of gelatin forming a stable colloidal suspension. But tannin is present in every fruit juice (its quantity showing wide differences with varieties and considerable differences in a single variety when grown in different years or under differing cultural and environmental conditions), and this tannin enters into the reaction with gelatin. For this reason the amounts of tannin and gelatin to be employed must be determined by experiment for every juice, and with such viscous materials as grape and apple juices the outcome of such experiments can be certainly determined only after some days. This alone makes the method impracticable. The further fact that the tannin of a juice plays an essential rôle in determining its characteristic flavor and that its removal results in marked alteration of flavor makes the

method useless for fruit juices. The same objections apply to the use of such materials as fish glue, egg albumen, milk, casein, and blood; the precipitation obtained with these substances is due to reaction with tannin or the acids present, or both, with consequent alteration of flavor.

As the work of La Marca (*16*) upon the effects of clarifying agents on the chemical composition of wines has shown, perceptible alteration in flavor as well as in chemical composition of the wine results from the employment of such materials, which led La Marca to advise strongly against their use by wine makers.

A rather careful study carried on in the laboratory of the Bureau of Plant Industry has yielded results showing conclusively that the use of any of the nitrogenous materials previously mentioned as a clarifying agent for unfermented fruit juices is highly inadvisable. The viscosity of most juices is sufficiently high to make the subsidence of the precipitate extremely slow and incomplete. All the substances used are complex protein mixtures containing constituents which are to some degree soluble in the juice, and the introduction of such sources of nitrogen makes the liquid a better medium for the growth of molds. The alteration of flavor produced by the loss of tannin and the introduction of foreign material is perceptible in all juices and amounts to denaturation in the case of the more delicately flavored ones. For these reasons the use of such methods with unfermented juices is ineffective and injurious.

CLARIFICATION BY THE USE OF INERT ADSORBING AGENTS.

The third group of methods for clarifying colloidal solutions or suspensions is that employing chemically inert solids as adsorbing agents. Methods of clarifying wine and vinegar and some other liquids by means of such materials as fuller's earth and Spanish clay have been developed empirically and have been in use for long periods, while the use of carbons in decolorizing cane juice has been discussed in the literature, according to Zerban (*34*), since 1785; but it is only very recently that much attention has been devoted to the study of solid adsorbents for clarifying fruit juices.

CARBONS AS CLARIFYING AGENTS FOR FRUIT JUICES.

The studies of solid adsorbents made in the laboratory of the Bureau of Plant Industry began in 1918 with a study of a considerable number of carbons, which included, with others, samples of a number of special filtering carbons supplied by American manufacturers and various samples of purified animal charcoals obtained through chemical supply houses. The work included the treatment of a large number of apple and grape juices, immediately after pressing or after

preliminary pasteurization and sedimentation, with various amounts of each of the carbons, followed by the removal of the carbon and the subsequent examination of the juices with respect to alteration of color and flavor, degree of removal of colloidal matter, and ability to withstand subsequent pasteurization without formation of precipitate. In view of the character of the results, a detailed statement of the experimental work is considered unnecessary, but a somewhat extended statement of the difficulties encountered may be made.

(1) In order to produce anything approaching a satisfactory subsidence of the precipitate after adding carbon it is necessary first to filter the juice, as Gore (*14*) has pointed out. The filtration of freshly pressed apple or grape juices by any of the ordinary methods is practically impossible, and even under high pressure is extremely slow and difficult, as the filter quickly becomes clogged with cellular débris and gummy material. The use of diatomaceous ("infusorial") earth, which Gore has suggested as an aid to this preliminary filtration, increases the rate somewhat, but does not eliminate entirely the clogging and frequent stoppage of filters of any of the usual types. With grape juice expressed after heating the fruit, it is a practical impossibility to make such filtration.

(2) The most marked property of all the carbons examined in the course of the work was their high decolorizing power for both apple and grape juices. While the samples differed markedly in this respect, the outstanding effect of carbon treatment was in every case a very considerable lightening of color. In very heavily pigmented red or purple grape juices this effect is not highly objectionable, but in juices made from white or light-red grapes and in apple juices the use of carbon produces very light straw-colored liquids, quite unrecognizable as to source. Since the available carbons of vegetable origin had been subjected to special treatments specifically designed to increase decolorizing power, as Zerban (*34*) has pointed out, this result was to be anticipated in so far as such special carbons are concerned, but the effect of boneblack upon the color of the lighter juices was also so pronounced as to make its use inadvisable except with very deeply colored juices.

(3) All the carbons employed have a perceptible effect upon flavor. In the case of some highly flavored, strongly foxy or musky juices, this effect, while perceptible, is not undesirable, but in delicately flavored grape juices and in apple juices it detracts materially from the beverage quality of the product. The alteration is due in most part to the adsorption of tannin and in less degree to the removal of acids by the carbon, as is shown by the decided improvement in flavor produced by restoring these constituents in amounts equal to those removed. But other unknown constituents which play a part in determining the characteristic flavors of the several juices are also removed. This is shown by the fact that juices "reconstituted" by additions of acid and tannin are always readily distinguished by taste even by inexperienced persons from untreated samples of the same variety. Treatment of the carbon prior to use by washing with a dilute solution of tannic acid in malic or tartaric acid reduced the effect in so far as these constituents are concerned, but it did not prevent perceptible alterations in flavor. La Marca (*16*) in his work upon the clarification of wines, found that the use of carbon reduced acidity, tannin content, and extractives, and Gore (*14*) has stated that when orange or lemon juices are treated with carbon "it is advantageous to add orange or lemon flavor, in the respective cases, to the respective juices prior to sterilization, in order to restore their

distinctive flavor." The results obtained by the Bureau of Plant Industry with a large number of apple and grape juices indicate that carbon has too much effect upon flavor to permit its use with apple juices or with any but the more strongly flavored grape juices.

(4) The various carbons differ materially in the degree of transparency which it is possible to produce in a given juice by their use. In part, these differences are due to differences in adsorbing surface presented by equal weights of material ground to unequal degrees of fineness, but in part they are specific differences due to differences in porosity, in ash content, or to other factors not controllable by separation of the samples into particles of like size by screening. The results indicate that the character and amount of ash in a given carbon may have considerable significance in determining the efficiency of the carbon in the removal of colloidal material of the nature here dealt with, namely, pectins and gums. A certain sample of animal charcoal, when prepared for use in the usual manner by treatment with hydrochloric acid and washing free of acid with water (*20*, p. 22; *31*, p. 88), gave a clearer, more brilliant product than any other carbon. When this charcoal was subjected to exhaustive treatment in order to remove salts as completely as possible, its clarifying efficiency was reduced practically to the level of other carbons. This, of course, suggested that it may be possible to improve the efficiency of carbons for the particular purpose here aimed at by preliminary chemical treatment, but the fact that carbons are not well adapted to the purpose in other respects made it appear inadvisable to follow up the suggestion, especially since Zerban and his associates (*34*, *36*, *37*) already have under investigation the broader problem of the particular property or constituent of carbons which gives them clarifying power.

(5) The removal of pectins and gums by carbon is very incomplete in the case of apple and grape juices, as Zerban (*34*) has shown to be the case in cane juices. Consequently, the pasteurization of juices clarified with carbon is followed by the formation of a considerable precipitate unless such juices have been subjected to preliminary pasteurization followed by the removal of the heat-coagulable material prior to treatment with carbon. This double pasteurization is to be avoided if possible, as it materially increases the labor and cost of handling, while at the same time increasing the loss of flavor.

(6) Considerable difficulty is encountered in dealing with viscous juices after the addition of carbon, even when subjected to preliminary pasteurization, as a result of the fact that a portion of the added carbon forms a persistent suspension in the liquid. This can not be removed by any of the usual methods of filtration, and when juices so treated are pasteurized and stored there is a slow deposition of carbon upon the sides and bottom of the containers. Gore (*14*) encountered this difficulty and found it necessary to add diatomaceous ("infusorial") earth and to filter in order to remove the carbon. His process as applied to the more difficult juices consequently involved a preliminary treatment with infusorial earth and filtration, treatment with carbon, a second treatment with earth, and a second filtration. As some time must be allowed to permit sedimentation after each step in the treatment, the process is laborious and requires rather careful temperature control to prevent fermentation. The repeated handling necessarily involves a greater danger of infection with mold spores and increases the difficulty of securing perfect pasteurization.

In view of the many serious difficulties encountered in the use of carbon and the decided denaturing effects upon color and flavor of all but the most strongly flavored and deeply colored juices, it

appears that such carbons as have been studied must be regarded as decolorizing agents rather than as potentially valuable aids in clarifying fruit juices.

GELATINOUS SILICA AS A CLARIFYING AGENT.

Deprax (*9*), in a brief popular note, has reported good results in the clarification of beers which had proved refractory to the usual fining with gelatin from the use of "gelatinous silica" prepared by precipitating an aqueous solution of an alkaline silicate by adding HCl or H_2SO_4, washing, filtering, and pressing. Though it is noted that certain conditions of concentration must be observed, these are not stated. The author also suggests that the process may be greatly simplified by the substitution of ammonia or ammoniacal salts for acids as precipitating agents, stating that the resulting mixture is as effective for clarifying purposes as the acid precipitate. Using 100 grams of the gel, containing 17 grams of dry silicic acid per hectoliter of beer, he reports that he obtains a relatively dense, rapidly formed, quick-settling precipitate. In exceptional cases, larger quantities are necessary, but Deprax states that large quantities might be used, since he has determined that the material is insoluble in the liquid.

An extensive literature has grown out of Martin's discovery (*19*) that colloids may be removed from their dispersion means by filtration through a suitably supported layer of silicic-acid gel, and every textbook of colloid chemistry devotes considerable space to ultrafiltration through this and similar gels as a means to this end. Little attention seems to have been given to the possibility of the use of silicic-acid gel as an adsorbing agent in the manner suggested by Deprax, and his note is the only record that it has been possible to find in the literature of an attempt to use it as a clarifying agent for beer or wine.

Deprax (*9*) gives no details as to the preparation of his material; it is clear, however, that when sodium or potassium silicate was treated with HCl or H_2SO_4, the precipitate consisted mainly of metasilicic acid, H_2SiO_3, with some orthosilicic acid, H_4SiO_4, containing sulphates or chlorids of sodium or potassium. When ammonium salts or NH_4OH were employed as precipitants, the resulting mixture of silicic acids contained sodium and potassium salts or hydroxids together with free ammonia. Since Deprax prepared his material by washing, filtering, and pressing, it is certain that all these impurities were present in the respective preparations.

In the work done in the laboratory of the Bureau of Plant Industry it has been found impossible to produce satisfactory clarification with silicic-acid gels. Such crude preparations as Deprax em-

ployed retain traces of salts even after very prolonged washing on a filter and can be purified only by dialysis. A portion of the material forms quite stable suspension in a fruit juice to which it is added, the precipitate forms very slowly, the removal of colloidal matter is imperfect, and the filtration of a juice so treated is almost impossible by reason of the prompt formation over the filtering surface of a slimy, well-nigh impervious layer. Silicic-acid gels prepared and purified by more exact methods also fail to give satisfactory clarification or to filter readily. The preparation of the gel involves too many difficulties, and its use yields results too far short of satisfaction to make it a promising material for use in clarifying fruit juices.

DIATOMACEOUS EARTH (KIESELGUHR) AS A CLARIFYING AGENT.

Diatomaceous ("infusorial") earth (kieselguhr)[2] has been recommended as a filtering agent for various liquids, and patents covering its use in clarifying cane juices were issued in both Great Britain and the United States as early as 1886 (*21*, p. 586). Its use for the purpose, either alone or in combination with other materials, has been repeatedly suggested in the older literature. More recently there has been a decided revival of interest in kieselguhr as a clarifying agent, as evidenced by a considerable number of papers and the patenting of several processes. Gore (*12*) recommended its use as an aid to the filtration of previously neutralized apple juice in making apple sirup and also as an aid in filtering fresh apple juices through a filter press (*13*). More recently Peck and Adams (*26*) have described a new carbon intended for use in clarifying cane juices, which is made by mixing molasses with kieselguhr, treating with sulphuric acid, baking, and washing free of acid. The material is reported to have very great decolorizing power and to give very considerable increase in purity with a reduction of gums to 30 to 45 per cent of the amounts present before treatment, which would suggest, in view of Zerban's results with carbons, that the kieselguhr aids very materially in the adsorption of gums.

Peck (*24*) has reported results obtained by the addition of kieselguhr to the juice at the rate of 5 pounds per ton of cane, with considerable increase in purity. The same author in an address has also made incidental mention (*25*) of the work of Walter L. Jordan in filtering juices through kieselguhr, stating that an increase in purity was obtained, but Peck gives neither details nor citation of Jordan's paper, which it has been impossible to locate in the litera-

[2] Since kieselguhr consists chiefly or wholly of the siliceous frustules of diatoms, it is unfortunate that the older and correct designations diatomaceous earth, diatomite, or tripolite, which suggest the origin and chemical character of the material, should have been replaced in trade usage by the wholly misleading term "infusorial earth."

ture. Norris and McAllep (*22*) have published a note on the use of diatomaceous earth as an aid to the filtration of small quantities of raw cane juice in the laboratory, using brass wire screen beneath the filter paper in a Buchner funnel. Heriot (*15*, p. 205–206) describes a method of employing kieselguhr on a factory scale in filtering cane juice. Zerban (*35*), whose paper cites a number of papers from the older literature on the use of kieselguhr, has reported the results of both laboratory and factory scale tests of a specially prepared diatomaceous earth, which was used in filtration of cane juice preparatory to filtering through carbon, with excellent results. Wooster (*33*) has patented a process of filtering raw cane juice which appears to be essentially identical with those of Peck (*25*) and Zerban (*35*), since it consists in the addition to the raw juice of kieselguhr and filtration through filter presses. Martel (*18*) has designed a leaf filter which is said to be highly effective in clarifying cane juice. The juice, as it comes from the mill, is mixed with specially prepared diatomaceous earth, agitated, heated nearly to boiling point, and forced into the filters at low pressure—30 pounds per square foot. Dale and Hudson (*8*) have described a process of clarification for use with sugar-cane juice in sirup manufacture, the juice being heated to boiling, mixed with diatomaceous earth at the rate of 5 to 6 pounds per hundred gallons, and immediately pumped through a plate-and-frame filter press. With smaller quantities of the earth, filtration was retarded by the formation of a slimy, almost impervious coating on the filter cloths. The method gave a better clarification than it was possible to obtain by the usual methods of straining and skimming, and the resulting sirup was considered superior in flavor to the usual commercial product. Coates (*6*) has reported satisfactory results from the use of diatomaceous earth at the rate of 12 to 16 pounds per ton in the filtration of tropical raw sugars in Louisiana sugar factories, the earth, previously made to a thin cream with water, being added to the sugar prior to melting.

Paine and Walton (*23*) have recently presented before the sugar section of the American Chemical Society a report of a comparative study of various diatomaceous earths with reference to their clarifying efficiency for cane juices, finding that considerable differences in physical properties do not materially affect the values of the various earths for this purpose.

Chace (*5*) has reported experiments upon grapefruit juices, in which satisfactory clarification is obtained by pasteurizing the freshly expressed juice, storing until sedimentation is completed, decanting, mixing with kieselguhr, filtering through cloth, bottling, and pasteurizing. Cruess (*7*) mentions the fact that diatomaceous earth may be used as an aid to the filtration of grape juices and

loganberry (Logan blackberry) juices, adding that it may affect flavor. As this author states elsewhere in the same publication that egg albumen, casein, and Spanish clay are the clarifying agents which have been found most satisfactory for use with fruit juices in his laboratory, he evidently did not consider that diatomaceous earth had possibilities for the purpose.

Wilson (*32*) in a very recent paper outlining the method of manufacture of citric acid from lemons, states that prepared diatomaceous earth is added to the raw juice, the liquid then being heated to boiling and passed hot through the filter press, which is said to deliver "a brilliant amber-colored juice."

EXPERIMENTS WITH DIATOMACEOUS EARTH FOR CLARIFYING FRUIT JUICES.

The writer's experimental work with diatomaceous earth was begun in the autumn of 1918, prior to the publication of the group of recent papers just cited and without knowledge of the work under way in the various laboratories from which they came. It was suggested, however, by such references to the use of diatomaceous earth in the clarification of cane juices as are found in the older standard handbooks on sugar manufacture. The possibilities of a material combining insolubility, a high degree of freedom from contaminating foreign matter, and immense absorbing surface were immediately obvious, and various samples of diatomaceous earth, of both American and foreign origin, were obtained for use in preliminary experiments. In these tests a relatively small number of apple and grape juices, selected so that they might fairly represent the range of variation in color and in physical characters found in these juices, were employed. All the tests in 1918 were made upon juices previously pasteurized and stored until sedimentation had ceased, but all were opaque, turbid solutions.

It was immediately apparent that diatomaceous earth combined excellent clarifying power with very slight or insignificant effect upon the coloring matter of apple and grape juices. In every case the effect of treatment with the earth was an apparent deepening of the color of the liquid due to its transparency after removal of the colloidal material, so that visitors to the laboratory refused to believe that treated juices had not been artificially colored. There was noticeable in all the more delicately flavored juices a peculiar alteration in taste, described by some as an "earthy" flavor, by others as a "rancid, old-butterlike" taste. This was more marked in samples treated with one of the lots of diatomaceous earth than in others but was perceptible in all. It was attributed to the presence of a soluble impurity in the earth. The fact that living diatoms contain amounts

of wax varying between 5 and 50 per cent by weight,[3] the relation of certain commercially employed upper Miocene deposits of diatomaceous earth to oil fields (*1*, *2*), and the character of the flavor imparted to juices indicated that the material might be a derivative of wax. This assumption was borne out by its behavior, but no attempt to isolate the material in quantity or to study it chemically was made. Attention was directed to the working out of simple methods for removing it with sufficient completeness to make the earth free from discoverable effect upon the flavor of the juices.

PURIFICATION OF THE EARTH.

Extraction of the earth with the usual fat solvents completely removed the material which gives foreign flavor to juices, but such treatment on other than an experimental scale is impracticable. Attempts to wash out the contaminating material in the manner recommended by some filter-press manufacturers, by stirring the earth into boiling water, decanting after settling, and repeating the process a few times, proved ineffective, as earth so treated still had perceptible effect upon the flavor of delicate juices after 10 or 12 changes of water. Earth boiled on a water bath for several days with repeated changes of water was not wholly freed of the contaminating material.

The most satisfactory method of purifying the earth was by incineration. In preliminary work small lots were placed in porcelain dishes, heated to low redness for 30 minutes in an electric furnace, allowed to cool, and rubbed through a sieve having 50 to 80 meshes per inch. For the preparation of larger lots a metal container made by capping one end of a 4-inch iron pipe 20 inches long and providing a loosely fitting plug for the opposite end was used. This was filled with the earth, plugged, placed in the fire box of a steam boiler, and allowed to remain for an hour. An ordinary heavy-walled steel kettle provided with a lid has also been used with satisfactory results. The traces of iron thus added to the earth are without discoverable effect upon the juices.

Purification by heating has the obvious advantage that it permits repeated use of the earth. On burning a quantity of earth which has become loaded with material derived from the juice an insignificant amount of ash remains in the earth, but this does not materially increase with repeated use. Carbon progressively accumulates with repeated burnings, ultimately becoming sufficient to exert an appreciable decolorizing effect upon juices filtered through it. In practice it has been found possible to use a single lot of earth 10 to 15 times, revivifying by burning after each use, before the carbon

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[3] Mann, Albert. Personal communication to the writer.

present begins to affect the color of the juices, and even after such prolonged use the earth may give considerable further service in treating heavily colored juices.

DIFFICULTIES ENCOUNTERED IN FILTERING TREATED JUICES.

In the earier work various treatments were employed in the attempt to devise satisfactory methods of filtration after treatment with the earth which would be usable on a small scale. Some difficulty in obtaining a perfectly transparent filtrate arises from the fact that diatomaceous earth contains a considerable quantity of excessively fine fragments of broken frustules which pass through ordinary filters and later partially settle out upon the walls of the containers. Lenher (*17*) has shown that when silica or orthoclase is ground until most of the particles are less than 0.004 mm. in diameter, shaken up in water, and allowed to stand for several weeks the larger portion of the suspended material settles quickly, but the finer particles form strata in the liquid which persist for 10 days. At the end of 15 days the solution is stable, but a portion of the material is in colloidal solution and shows Brownian movement and Tyndall effect. It is clear from results obtained in the laboratory that analogous conditions result when diatomaceous earth containing minute fragments of broken frustules is added to a fruit juice, as a progressive settling extending over some days or weeks occurs when a sample of treated juice which has been filtered through paper is allowed to stand undisturbed.

As the centrifuge is successfully used in a wide variety of otherwise difficult separations and has repeatedly been suggested as a substitute for filtration in the clearing of fruit juices (*11*), its possibilities as a means for clarifying ciders treated with diatomaceous earth were thoroughly tested. After being thoroughly mixed with the earth, the juices were repeatedly passed through a gear-driven laboratory supercentrifuge having a maximum speed of 25,000 revolutions per minute. A single passage through the machine was practically as effective as three or more, since only a very small trace of material was recovered by any treatment after the first. While the appearance of treated juices was greatly improved, a considerable amount of colloidal material remained in suspension even after repeated stirring with earth followed by passage through the centrifuge. Juices so treated and subsequently pasteurized and stored remained for 18 months as hazy colloidal solutions. Attempts further to clarify such centrifuged juices by ordinary filtration were unsuccessful, as any filter having sufficiently close texture to hold back the suspended particles quickly became choked by slime.

For these reasons the complete removal of the added earth from the juices by any of the more generally available methods of filtration appeared somewhat difficult at the outset. The best types of

plate-and-frame filter presses handle such filtration problems successfully, but the cost of such equipment limits its use to commercial-size installations. A pulp filter operated by a steam suction pump failed to give satisfactory results. When first started, such a filter permits the passage of particles of earth; by the time this ceases the surface of the pulp has become coated with a slimy, almost impervious layer, and filtration becomes extremely slow. Increasing the suction upon the filter merely hastens clogging by making this slimy layer more compact. Attempts to use a small multiple-disk pulp filter fed by gravity were equally unsuccessful; clogging and stoppage occurred very quickly under gravity pressures ranging from one-fourth to two atmospheres. The difficulty with such filters is twofold. The filtering medium is not sufficiently close in texture to retain the finer particles until it has become reinforced by a layer of earth. As the earth settles out of the undisturbed liquid, the larger and heavier particles come down first, followed by the deposition of successive strata of finer and finer particles. Such a layer of earth is a highly efficient filtering medium in so far as preventing the passage of suspended material is concerned, but its working period is short, for the reason that there is soon built up on the surface a layer of gummy, viscous material which practically stops the flow and necessitates cleaning and repacking the filter. No satisfactory method of overcoming this twofold difficulty in the use of pulp filters either of the gravity or of the suction type has been found.

SIMPLE AND EFFECTIVE METHODS OF FILTRATION WITH DIATOMACEOUS EARTH.

SMALL MULTIPLE-DISK FILTER.

As a plate-and-frame type of filter press was not available in the laboratory, a small multiple-disk pulp filter was so modified as to make it essentially a plate-and-frame filter. The circular pulp disks were replaced by filter cloths of a closely woven, rather light denim, fastened in place at the outer edge and around the central opening by rubber gaskets. When all were in place the press was closed and water was passed through to wet the cloths thoroughly. A quantity of earth sufficient to coat the cloths to a depth of about 0.5 cm. was then thoroughly stirred into water and passed into the press. As the filter was of the vertical type in which the disks rest one upon another like a pile of coins, it was easy to effect uniform distribution of the earth over the cloths by running it in while in suspension in water under a head of 6 to 10 feet. Water was then passed in until earth ceased to wash through. The juice to be filtered was then stirred thoroughly with diatomaceous earth at the rate of two-thirds to 1 ounce per gallon (4 to 6 pounds per hundred gallons) and passed into

the filter from a feed tank with a gravity head of 10 to 12 feet. The juice in the feed tank was vigorously stirred from time to time to maintain a uniform suspension and prevent the clogging of the feed line. The filtrate was clear and brilliant; filtration was quite rapid and was maintained at an almost uniform rate until the press had become completely filled with quite compact cakes. As the filter was not so constructed as to permit thorough cleaning by back flushing, it was necessary to open the press to clean it, but the cakes could be turned off the cloths practically entire, the cloths washed and replaced, and the press made ready for a second run in considerably less time than was required to clean and repack the same press with filter pulp.

SUGGESTIONS FOR THE MANUFACTURE OF A SMALL FILTER.

If the makers of filtering equipment would devote some attention to the manufacture of filtering devices suited to use with diatomaceous earth which would have the efficiency of some of the small laboratory filters now made for experimental use, placing them on the market in a range of sizes and at prices which would put them within reach of fruit growers and small operators who make a few hundred to a few thousand gallons of cider or grape juice annually, they should find a very considerable market. Such filters might be of any one of several types. A wooden plate-and-frame press to be fed either by a pump or under a gravity pressure of 12 to 15 pounds, so constructed as to permit cleaning by back flushing, should give satisfactory results. The vertical multiple-disk filter, consisting of a series of superposed metal plates each carrying a disk of filter pulp, if modified so as to permit the substitution for pulp of readily attached filter cloths and to provide for the removal of the cake by back flushing with water, should also be efficient, as the vertical position of the filter areas facilitates deposition of a uniform film of earth over them and secures uniform cakes free from channels. A further advantageous modification of this type would be the deepening of the chambers so as to give space for thicker cakes. Such a filter might be operated either by gravity or by a pump.

The leaf filter has a number of features which lend themselves very advantageously to the filtration of fruit juices and which make it possible to construct inexpensive filters of small capacity. The leaf type of construction makes it possible to obtain a large filtering area in a small apparatus, while the fact that filtration is from without inward permits the quick cleaning of the filter cloths as they become clogged without removing them from the frames. Such a filter might be made up in units of two or more leaves, to be installed by the user in any suitable tank and operated either by suction or by gravity, at very moderate cost.

SIMPLE METHODS FOR USE WITHOUT SPECIAL EQUIPMENT.

In the absence on the market of any suitable small-capacity press adapted to the handling of juices with diatomaceous earth, some time was devoted to the working out of methods by which the small operator without special equipment could avail himself of the advantages offered by the use of earth. The purpose in view was to devise an arrangement in which filtration would occur through a layer of earth which could be kept from clogging. Clogging can be effectively prevented by keeping the mixture of earth and liquid thoroughly agitated, thus securing the constant renewal of the filtering surface by deposition of the solid particles of earth in mixture with the amorphous suspended material of the juice. Without such provision for agitation the larger particles of earth would quickly come down, after which clogging by the amorphous slimy matter arrested at the surface would soon occur. It was necessary also to make provision for the easy and quick cleaning of the filter or the renewal of the filtering layer.

A LABORATORY FILTER.

A very simple arrangement meeting these requirements and using a compact layer of earth as a filtering medium has been in use in this laboratory for some time. It yields a permanently clear filtrate at a satisfactory rate and is readily cleaned when necessary. In the first small filter made for use in the laboratory, a piece of 100-mesh nickel-wire gauze was cut to fit as closely as possible into a large Buchner funnel. A quantity of diatomaceous earth was made up into a thick paste with water, spread upon the gauze in a layer 2 to 3 cm. thick, packed under gentle suction, and washed with water until earth ceased to come through, care being taken to keep the surface of the layer of earth as smooth as possible. Filtration was then begun. The juice to be filtered was mixed with diatomaceous earth, stirred thoroughly, and immediately poured on the filter. Care was taken to repeat the stirring of the liquid every time the filter was refilled. When the formation of a layer of slime over the surface materially reduces the rate of filtration, the filter is allowed to empty itself, a thin film of earth carrying with it the gummy deposit is removed with a spatula or similar instrument and stored for revivification by burning, and filtration is resumed. By making the layer of earth 2 to 3 cm. thick at the outset and packing it firmly, this treatment can be repeated almost indefinitely, as the material which causes clogging is practically wholly arrested at the surface, penetrating at most only a millimeter or two into a properly packed disk.

A FILTER FOR USE ON A SEMICOMMERCIAL SCALE.

A similar arrangement for use on a larger or semicommercial scale was made from a pulp filter operated by a steam suction pump by removing the pulp packing and replacing it with a heavy nickel-wire screen fastened permanently in place. Upon this as a support was placed a piece of heavy closely woven denim. Diatomaceous earth in the form of a thick paste was then poured in and packed into a firm disk about 3 to 3½ cm. thick by gentle suction and pressing down with a wooden rammer. A few minutes' washing with water under full suction removed all traces of earth from the lower surface of the cloth. Such an arrangement filters rapidly, can be restored to the original rate of filtration when partial clogging occurs by scraping off the accumulated slime together with a thin layer of the compact disk, and when necessary can be taken out and replaced in a very short time. In setting up and operating such a filter it is necessary to observe a few rather obvious precautions. The wire screen used as a support should be of a metal which is not attacked by the acids of the juice, though in default of a satisfactory screen a wooden lattice may be used. Whatever the material used, the support must be rigid, in order that the filter disk may not be displaced or broken by starting or stopping the suction pump. The cloth used as a backing should be of firm closely woven texture, in order that particles of the earth may not wash through it into the filtrate, and should be thoroughly wetted before it is put into place. The earth used in packing the filter should be made into a paste with as little water as possible, as it then holds together like putty, does not pass through the cloth, and can readily be molded into a uniform layer, making close contact with the side walls of the container. When the earth is so packed very little washing is necessary. In filling the filter with juice, care must be taken not to allow the entering stream to strike the disk with sufficient force to wash holes in it. The liquid on the filter should be thoroughly stirred from time to time. Care must be taken not to allow the disk to become dry, as the earth then shrinks considerably and will crack and pull away from the side walls of the container if not kept thoroughly moist. In cleaning the surface of the filter when it becomes coated with slime, a broad-bladed putty knife or some similar instrument which permits the operator to pare off a uniform thin layer from the top of the disk should be employed. When the removal of the disk is necessary it should be allowed to become rather dry; it may then be lifted out practically entire. The cloth used as a backing should be taken out and thoroughly washed before the filter is replaced. The disks which have become clogged from use, together

with the material accumulated by scraping the filter, are preserved and burned for subsequent use.

It will be seen from the foregoing description that this arrangement gives essentially the advantages obtained by the use of molded silica filtering plates, with the differences that the material used is inexpensive and may be used over and over again practically without loss; that there is no danger from breakage, as in the case of filter plates; that cleaning and replacement are matters of a few minutes' work only; and that the filtering disks may be made of any size or shape desired by the individual operator, who may readily make one or more filters of any desired capacity to suit his needs.

A FILTER FOR HOUSEHOLD USE.

For handling small quantities of juice, such as would be put up for individual household use, where a suction pump is not available, very satisfactory results are obtained by gravity filtration through a disk of earth. The vessel used should be a deep one, in order that the column of liquid upon the filter may be heavy enough to aid filtration; for this reason also the vessel should be kept full while filtration is going on. A cask provided with a false bottom for supporting the filter and a faucet placed just below it for drawing off the juice serves very well. The filter disk should be made somewhat thicker than would be the case in a filter operated by suction and greater care must be employed to pack the earth firmly over the whole surface and especially along the walls of the container. Caution must be employed in filling the filter for the first time, in order not to wash holes in the layer of earth; it is well to place a wooden float in the vessel and to pour the juice upon it, as the disk of a gravity filter, unlike that of a suction filter, becomes less rather than more compact in use. For this reason there is less choking, and a gravity filter under a head of 2 feet of liquid will run at a practically uniform rate for a long period, as there is much less tendency to form a compact slime layer over the surface than when suction is used.

A FILTER OF THE JELLY-BAG TYPE.

A device of the jelly-bag type permits quite satisfactory filtration of small quantities which would not justify the making of a more elaborate filter. The bag should be made of heavy closely woven denim and should have the form of a rather tall cone. The seam should be double and should preferably be made by machine in order to guard against leakage. After wetting the bag thoroughly, it should be suspended and such a quantity of earth, previously made into a thin paste with water, poured into it as will practically fill it. After the water has drained away the treatment should be repeated,

if necessary, in order to cover the entire inner surface of the bag with an adhering layer of earth, after which water is passed through until the outer surface is washed free of the earth. The filter is then ready for use. It is well to keep the bag practically full to the top, not only in order that the entire filtering surface may be used, but also because of the more rapid filtration per unit area resulting from the greater weight on the surface. While satisfactory clarification is obtained with such an arrangement, its use should be confined to the handling of very small quantities.

PASTEURIZING BEFORE FILTERING.

In the earlier experiments with diatomaceous earth, in the seasons of 1918 and 1919, the juices employed were in all cases pasteurized immediately after pressing and were subsequently stored until the settling out of cellular débris and heat-coagulable material had become fairly complete before attempts to clarify them were made. The length of the storage period was determined by convenience and the pressure of other work, ranging from four weeks to nine months as extremes. Sedimentation was usually complete at the end of three weeks in the storage room, which was a room in the laboratory building with no means of temperature control other than a steam coil to prevent freezing in severe weather.

In some cases the juice, after being decanted from the sediment in the containers, was placed in a large vessel, thoroughly mixed with the earth by prolonged stirring, and allowed to remain undisturbed for several hours or overnight. It was then decanted with as little disturbance of the sediment as possible, mixed with a second smaller quantity of earth, and at once filtered. In other cases the juice was mixed with the earth, allowed to stand for 10 to 15 minutes with occasional stirring, and filtered without permitting settling to occur. As this treatment gave as satisfactory results as the other, all the juices dealt with in the later work were filtered as soon as convenient after being mixed with the earth.

Juices treated in this manner were brilliantly clear and remained transparent after being bottled, pasteurized, and stored for more than 12 months in a laboratory room subject to wide fluctuations of temperature. The characteristic flavors of juices so treated are not injuriously affected.

FILTRATION OF FRESHLY PRESSED JUICES.

Success in the treatment of juices which had previously been pasteurized and stored led to the hope that it might be possible to apply the treatment to freshly expressed juices, thus dispensing with storage and making the whole process of preserving fruit juices a continuous one, in which pressing should be followed immediately by

filtration and then by pasteurization in the final containers. A few preliminary experiments in the season of 1919 gave some encouragement to this idea, which was fairly thoroughly tested in the autumn of 1920. Several methods of handling the juices were employed. These will be outlined and their advantages and disadvantages indicated.

TREATMENT WITH EARTH, FOLLOWED BY SEDIMENTATION, BEFORE FILTERING.

In order to ascertain whether mixing with diatomaceous earth, sedimentation, and decantation prior to filtration would be advantageous, a quantity of juice was divided into three lots. One of these was strained through cotton cloth, to remove fragments of pulp as completely as possible, and was then thoroughly mixed with the earth at the rate of 1 ounce of earth per gallon (6 pounds per hundred gallons). The second portion received an equal quantity of earth but was not previously strained to remove the pulp. The third lot was neither strained nor mixed with earth. The three lots were then placed in 5-gallon carboys, which were filled to the neck, corked, and placed in a basement room at a temperature of 55° F. for 18 hours, to allow sedimentation to occur. At the end of this time the lot which had received no treatment showed a fairly compact precipitate about 2 inches thick at the bottom of a 5-gallon carboy; the other two lots showed compact deposits 3 to 3½ inches thick, above which was a zone of less closely aggregated material, followed by poorly defined zones, each containing less suspended material than the next below. In this respect the lot which had been strained through cloth showed little, if any, difference from the unstrained lot. On carefully siphoning off the liquid it was possible to draw off 4⅝ gallons from the untreated carboy without greatly disturbing the sediment. Of the lots treated with earth, it was possible to draw off only 4¼ gallons from the lot which had been strained prior to the addition of earth, and 4⅛ gallons from that which had not been strained, before the liquid flowing from the siphon became very densely turbid from the drawing up of loosely aggregated material. There was consequently twice as much sludge in the case of treated juices, but it was of a very much less compact character.

Each of the three lots of juice was next treated with earth at the rate of 1 ounce per gallon, thoroughly stirred, and immediately filtered through a disk of earth with suction, the sludge from each lot being placed on the filter and drained as completely as possible after the siphoned liquid had passed through. A fresh filter disk was prepared for each lot, and uniform suction was employed throughout. The filtrates were equally brilliant. The juice which had not received a preliminary treatment with earth required about

10 per cent more time to pass through the filter, as a result of a greater tendency to clog the disk with slime, but gave a slightly greater yield of filtered juice than the others, since it was possible to reduce the sludge to a drier condition. The juices which had received the preliminary treatment filtered more quickly and with less clogging, but the bulky sludges could not be satisfactorily filtered dry.

In other experiments juices treated with earth were held for longer periods at lower temperatures, in order to prevent fermentation while allowing sedimentation to become complete. Here one encounters a difficulty arising out of the fact that as the temperature at which the juice is held is lowered, the viscosity of the liquid is increased, slowing down the rate of sedimentation and making it less complete.

A rather extended series of experiments has shown conclusively that the additional handling necessary and the greater loss of juice resulting from inability to filter the sludges satisfactorily make a preliminary treatment with earth followed by sedimentation before filtering inadvisable. A larger yield of filtered juice is obtained with a smaller expenditure of labor when the juice is allowed to stand undisturbed for 12 to 24 hours after pressing in order to allow the settling out of cellular débris, then decanted, mixed thoroughly with earth, and immediately filtered.

SEDIMENTATION BEFORE FILTERING.

A period of sedimentation before filtering is quite necessary and should never be omitted if an effort to obtain a perfectly permanent, clear, brilliant filtrate is being made. When either apple or grape juice is taken directly from the press, mixed with earth, and filtered, the liquid coming through the filter is perfectly transparent. On bottling and pasteurizing such juices and allowing them to stand for some time, however, cloudiness or haziness appears. The degree of the change varies greatly with various fruits, but all juices so treated become in some degree turbid colloidal solutions, while in some cases a deposit is ultimately formed in the bottles. Check samples of the same juices allowed to stand for 12 to 24 hours before treatment do not show this behavior, but remain permanently free from cloudiness or sediment.

The explanation of the facts just stated is not known, and only unproved hypotheses can be suggested. When the cells of the fruit are ruptured and the juice expressed and exposed to the air various constituents are brought together which were previously separated from one another in the cells but which are capable of reacting when brought into contact. The intercellular materials (pectin and its derivatives) are brought into contact with the acids of the juices and with pectase. It is conceivable that under such conditions a conversion of

the soluble pectin into a colloidal suspension may occur. Whatever the nature of the reaction, it is clear that it becomes complete within 24 hours at temperatures approximating 40° F., and in a shorter period at higher temperatures, becoming complete in a few minutes when juices are heated to the temperature of pasteurization. Consequently, if juices are held in the settling tank overnight, or for 24 hours if the temperature is low enough to prevent fermentation, and are then decanted, clarified, and bottled, no difficulty due to subsequent clouding of the liquid in the bottles will be encountered.

EXPEDIENTS TO SHORTEN THE PROCESS.

Various expedients have been resorted to in the course of the work in attempts to increase the ease of filtration or to shorten the process by permitting clarification and bottling immediately after pressing. Some of these gave negative results and are mentioned only in order that they may be avoided by others; some are advantageous if properly employed.

HEATING THE JUICE BEFORE FILTERING.

Heating the juice prior to filtration has many obvious advantages, chief among which are the precipitation of heat-coagulable constituents and the lowering of the viscosity of the liquid thereby produced. Hot filtration, however, is of very definitely limited applicability to fruit juices. It can be advantageously employed only for such juices as do not readily lose their characteristic flavors on heating and subsequent exposure to the air while hot. Such grape juices as those of Concord, Norton, Clinton, Clevener, Early Victor, Worden, Ives, Diogenes, Moore (*Moore's Early*), Cynthiana, Montefiore, and Niagara are not injured in quality or flavor by such treatment, which makes possible the usual commercial practice of crushing the grapes and heating to 175° F. in kettles prior to pressing. With all of these varieties excellent results are obtained by hot filtration. If the grapes are heated before pressing, the hot juice is taken directly from the press, thoroughly mixed with the earth, and immediately passed through the filter. If the grapes are pressed cold, the juice is at once heated to 165° to 175° F., mixed with the earth, and filtered. The juice obtained from any given variety by pressing cold is, of course, quite different from that obtained from heated grapes, but such juices are not injuriously affected by subsequent heating and hot filtration.

This method of treatment can not be employed with apple juice or with the more delicately flavored grape juices without considerable loss in quality. Juices of such varieties of grapes as Agawam, Brighton, Barry, Catawba, Delaware, Diana, Goethe, Elvira, Eumelan, Isabella, Lady, Massasoit, Missouri Riesling, Noah, Salem,

Rommel, Wilder, and Woodruff show material alteration in flavor after heating to 175° F. and filtering. There is also perceptible alteration in the flavor of apple juice, irrespective of variety, when so treated. The alteration in flavor is apparently identical with that which occurs when such juices are heated to pasteurizing temperatures in open vessels and is undoubtedly due to the loss of volatile constituents from the hot liquid during the unavoidable exposure to the air which occurs during filtering.

Experiments designed to determine the degree to which the heating of apple juices and the more easily injured grape juices may be carried without noticeable loss of characteristic flavor and quality indicate that the danger line for such juices lies between 130° and 140° F., when the liquid is slowly raised to this temperature in a tank heated by a steam coil or by placing it in open vessels sunk nearly to the top in a water bath. Juices heated to 130° F. in this manner, mixed with earth, and filtered hot showed no alteration in flavor. When heated to 140° F. and filtered while hot, such apple juices as those of York Imperial, Northern Spy, and Grimes, and such grape juices as those of Delaware, Isabella, Missouri Riesling, and Rommel were not perceptibly changed in flavor, while with such apple juices as those of Delicious and Winesap and such grape juices as Catawba, Goethe, Salem, Brilliant, and Brighton there was a distinct diminution in flavor. In the case of all these juices there was quite marked alteration in flavor in the lots heated to 150° F. before filtering, and the effect became more pronounced with the increase of the time during which the samples were kept at this temperature.

For these reasons, heating as an aid to filtration can be recommended only in cases in which the temperature can be rather closely controlled, and in no case should it be allowed to rise above 130° to 140° F. or to remain at this temperature more than a minute or two. Heating to these temperatures is insufficient to cause precipitation of the heat-coagulable material present in the juice, but very considerably increases the rate of filtration by diminishing the viscosity of the juice.

EXPERIMENTS WITH GRAPEFRUIT JUICES.

In the work with grapefruit juices reported by Chace (*5*), the juices were pressed, pasteurized, stored for some weeks until sedimentation had become fairly complete, decanted, mixed with diatomaceous earth, filtered, bottled, and pasteurized. It occurred to the writer that it might be possible to eliminate the preliminary pasteurization and subsequent period of storage in the case of grapefruit juice by applying to the freshly pressed juice the same methods found effective with apple and grape juices. This it has been possible to do.

Experiments with grapefruit juice were made at three periods in the life of the fruit, employing portions of the same lot of fruit. The first samples of juice were made on receipt of the fruit from the growers on November 9, the second on February 21, after the fruit had been in cold storage for 104 days, and the third on May 2, when the fruit had been in cold storage 174 days. The last lot of fruit had reached the limit of its life in storage and was in bad condition; pressing was difficult and the juice contained large quantities of pulp with a reduced yield, but clarification involved no difficulties. The treatment given the three lots was identical and the results were equally satisfactory; hence, an outline of one experiment only will be given.

The fruit was peeled, freed from adhering rag as completely as possible, passed through an apple grater, and pressed with a commercial hydraulic press. The juice was placed in deep containers and allowed to stand 18 hours for sedimentation to occur, after which it was decanted from the sediment. A portion was bottled and pasteurized, to serve for comparative purposes, and the remainder divided into portions of 10 gallons each. One of these was mixed with diatomaceous earth and at once passed through layers of earth supported on cloths in the disk filter press used in experiments with apple juice. The filtration was rather slow, but the product was entirely clear when bottled and pasteurized. The second lot was divided into two parts, one of which was mixed with earth, heated in an open vessel to 168° F., and filtered through freshly prepared earth filter plates in the same filter. This filtered more rapidly than the first lot, was equally clear, and showed no alteration in flavor. For purposes of comparison the remaining portion was heated to 168° F. without the addition of earth and filtered while hot through a closely packed pulp filter. As the filtrate was turbid and opaque, it was passed six times through the filter in an unsuccessful effort to improve its appearance. All the lots were then bottled and pasteurized in a hot-water tank at 168° F. for 30 minutes. Quart bottles of the untreated juice threw down a heavy precipitate upon standing and remained densely opaque after eight months' standing in a laboratory room. The juice filtered repeatedly through pulp while hot deposited a less heavy but considerable precipitate and held in suspension sufficient quantities of material to make the solution permanently opaque and tawny yellow in color. The juices filtered with the addition of diatomaceous earth, with or without subsequent heating prior to filtering, remained after eight months perfectly transparent and without a trace of precipitate, with a color suggesting that of olive oil and with a flavor indistinguishable from that of the untreated juice. It is consequently possible to shorten the process

of clarification and bottling with grapefruit juice by the employment of the same general methods found successful for apple and grape juices.

SUMMARY.

(1) The usual methods of filtration do not give satisfactory results when applied to unfermented apple, grape, and grapefruit juices, as such juices are difficult to filter and contain considerable quantities of colloidal material which pass through ordinary filters.

(2) Various methods of treatment designed to assist the clarification of these juices have been studied with a view to developing a means of making clear, transparent juices which would be applicable on a small scale.

(3) Clarification by means of enzyms can be accomplished, but the technical skill and the degree of control of conditions required in the work are such that the method is not adapted to general use in small-scale juice manufacture.

(4) The methods of clarification employed by wine makers, such as the addition of tannin and gelatin, casein, fish glue, egg albumen, and blood, should not be employed with unfermented apple and grape juices. Precipitation is slow and incomplete, the chemical composition of the juices is altered, and the palatability and flavor are decreased.

(5) Of the inert adsorbing agents used as aids in clarification, carbon is not suited for use with apple and grape juices. Carbons remove flavoring substances and have high decolorizing power and do not wholly remove pectins and gums. Carbon also forms persistent suspensions which pass through ordinary filters and ultimately deposit upon the sides of the container.

(6) The preparation of a suitable silicic-acid gel is tedious and difficult, the precipitation of colloidal material obtained by its use is imperfect and slow, and the filtration of juices so treated is difficult because of the prompt clogging of filters.

(7) Diatomaceous earth is by far the most satisfactory aid to the filtration of fruit juices yet employed. It is highly efficient in the removal of colloidal materials and does not remove coloring and flavoring substances.

(8) As obtained in the markets, diatomaceous earth contains varying amounts of wax derivatives which impart perceptible foreign flavors to most juices. These objectionable materials are readily removed by heating the earth to redness for a short time. Earth which has been used may be repeatedly "revivified" for further use by a similar treatment.

(9) Juices which are to be clarified by the use of diatomaceous earth should be allowed to stand undisturbed for 12 to 18 hours

after pressing, in order to permit the settling of cellular débris, and should then be siphoned or decanted from the sediment.

(10) The best results are obtained when the juices are thoroughly mixed with the diatomaceous earth at the rate of 6 to 8 pounds per 100 gallons and immediately filtered through a properly supported layer of the earth.

(11) During the filtration the juice on the filter should be thoroughly agitated occasionally, to keep the earth in suspension and prevent the sliming and choking of the filter.

(12) A number of filtering devices have been found satisfactory for use in filtering treated juices. The construction and operation of simple but effective filters adapted to use in home or semicommercial operations are described. Filters employing pulp are not suited to the purpose.

(13) Heating the liquid prior to mixing with the earth and filtering considerably increases the rate of filtration. If heating is conducted in open vessels or tanks, the temperature of the juice should not be allowed to exceed 130° to 140° F. and should not be long maintained at this temperature in the case of apple juices and the more delicately flavored grape juices or deterioration in flavor will occur. A few varieties of grapes yield juices which may be heated to 170° F. in open vessels without loss of flavor.

(14) Juices filtered with the aid of properly prepared diatomaceous earth on a suitable filter after previous sedimentation for 12 to 18 hours remain perfectly clear and transparent when bottled and pasteurized and retain the characteristic flavor and quality of the fresh juices in high degree.

(15) The employment of the methods of treatment herein described materially reduces the labor of preparing apple, grape, and grapefruit juices by eliminating preliminary pasteurization and storage in order to permit sedimentation, thus shortening the process of preparation and making it a continuous process. Losses from spoilage and breakage during this storage period are eliminated by making packing in the final containers possible; and a material improvement in the appearance of the product, together with a better preservation of flavor, is obtained.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 1001

Contribution from the Office of Farm Management and Farm Economics
H. C. TAYLOR, Chief

Washington, D. C. February 23, 1922

THE RELATION OF LAND TENURE TO THE USE OF THE ARID GRAZING LANDS OF THE SOUTHWESTERN STATES

By

E. O. WOOTON, Assistant Agricultural Economist

(Section of Land Economics, L. C. GRAY, Economist in Charge)

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 1003

Contribution from the Bureau of Chemistry
W. G. CAMPBELL, Acting Chief

And the University of Idaho, A. H. UPHAM, President

Washington, D. C. ▼ December 5, 1921

THE DISTILLATION OF STUMPWOOD AND LOGGING WASTE OF WESTERN YELLOW PINE

By

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1921

UNITED STATES DEPARTMENT OF AGRICULTURE

DEPARTMENT BULLETIN No. 1004

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USE OF WATER BY SPRING WHEAT ON THE GREAT PLAINS

By

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UNITED STATES DEPARTMENT OF AGRICULTURE
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Contribution from the Bureau of Soils
MILTON WHITNEY, Chief

Washington, D. C. ▼ April 24, 1922

SOILS OF EASTERN VIRGINIA AND THEIR USES FOR TRUCK CROP PRODUCTION

By

J. A. BONSTEEL, Scientist in Soil Survey

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UTILIZATION OF BASSWOOD

By

WARREN D. BRUSH, Scientific Assistant

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REPORT ON DRAINAGE AND PREVENTION OF OVERFLOW IN THE VALLEY OF THE RED RIVER OF THE NORTH

By

P. T. SIMONS, Senior Drainage Engineer
FOREST V. KING, Drainage Engineer

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Contribution from the Bureau of Markets and Crop Estimates
H. C. TAYLOR, Chief

Washington, D. C. April 14, 1922

MARKETING BROOM CORN

By

G. B. ALGUIRE
Assistant in Marketing Hay and Broom Corn

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Contribution from the Office of Farm Management and Farm Economics
G. W. FORSTER, Acting Chief

Washington, D. C. ▼ April 12, 1922

HARVEST LABOR PROBLEMS IN THE WHEAT BELT

By
D. D. LESCOHIER
Collaborator

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Contribution from the Bureau of Plant Industry
WM. A. TAYLOR, Chief

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GROUP CLASSIFICATION AND VARIETAL DESCRIPTIONS OF AMERICAN VARIETIES OF SWEET POTATOES

By

H. C. THOMPSON, formerly Horticulturist, and JAMES H. BEATTIE, Horticulturist, Office of Horticultural and Pomological Investigations

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Contribution from the Bureau of Plant Industry
WM. A. TAYLOR, Chief

Washington, D. C. ▼ February 3, 1922

RELATION OF INITIAL TEMPERATURE TO PRESSURE, VACUUM, AND TEMPERATURE CHANGES IN THE CONTAINER DURING CANNING OPERATIONS

By

C. A. MAGOON and C. W. CULPEPPER

Office of Horticultural and Pomological Investigations

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